RESEARCH PUBLICATION No.29

Torres Strait Baseline Study: Pilot Study Final Report June 1993

Trace Metal Concentrations in Sediments and Selected Marine Biota as Indicator Organisms and Food Items in the Diet of Torres Strait Islanders and Coastal Papuans

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A REPORT TO THE GREAT BARRIER REEF MARINE PARK AUTHORITY

ISSN 1037-1508
ISBN 0 642 17387 7
Published August 1993
by the Great Barrier Reef Marine Park Authority
Reprinted with corrections 1994
Reprinted with additions July 1994

National Library of Australia Cataloguing-in-Publication data:

Dight, I. J., 1948-
Torres Strait Baseline Study pilot study final report June 1993: trace metal concentrations in sediments and selected marine biota as indicator organisms and food items in the diet of Torres Strait Islanders and coastal Papuans.

Bibliography
ISBN 0 642 17387 7
1. Trace elements - Environmental aspects - Torres Strait. 2. Aquatic animals - Effect of water pollution on - Torres Strait. 3. Aquatic plants - Effect of water pollution on - Torres Strait. 4. Trace elements in the body. I. Gladstone, William, 1956- II. Great Barrier Reef Marine Park Authority (Australia). III. Torres Strait Baseline Study. IV. Title: Trace metal concentrations in sediments and selected marine biota as indicator organisms and food items in the diet of Torres Strait Islanders and coastal Papuans. (Series : Research publication (Great Barrier Reef Marine Park Authority (Australia)); no. 29).

363.7394099438

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EXECUTIVE SUMMARY

1. The Torres Strait Baseline Study (TSBS) has involved an initial pilot sampling programme which consisted of the collection of sediments and biota. The objectives of the pilot study included: (a) the identification of animals and plants which would be suitable indicators of variation in environmental trace metal concentrations for the main study; (b) an assessment of the distribution and variance in trace metal concentrations in sediments and biota from the Torres Strait such that the sampling programme and strategies for the main study could be refined; and (c) a preliminary assessment of the impacts of present levels of trace metals in marine biota on the health of Torres Strait Islanders and coastal Papuans. This report presents results which relate to objectives (a), (b) and (c) above.

2. Results are presented for: (1) sediments; (2) a wide range of biota, including two species of seagrass (*Thalassia hemprichii* and *Thalassodendron ciliatum*), six species of bivalve mollusc (the boring clam *Tridacna crocea*, the rugose giant clam *Tridacna maxima*, the black-lip pearl oyster *Pinctata margaritifera*, the zig-zag oyster *Hyotissa hyotis*, the jewel-box oyster *Chama plinthota* and the mangrove cockle *Polymesoda erosa*), two species of gastropod mollusc (*Trochus niloticus* and the red-lipped stromb *Strombus luhuanus*), the sea cucumber *Stichopus chloronotus*, and the stripey reef fish *Lutjanus carponotatus*; and (3) a range of marine animals which comprise important food items for Torres Strait Islanders and coastal Papuans. Samples for (1) and (2) above were collected from a range of locations during two sampling periods: the pre-monsoon (September-October, 1991) and post-monsoon (April-May, 1992) seasons. Community fishery samples were collected over a period of nine months from June 1991.

3. Sediment samples identify the Fly River as a major source of fine-grained sediment containing a suite of major and trace metals (including aluminium, cobalt, chromium, copper, iron, manganese, nickel, lead, silica and zinc) to the northern Torres Strait. Arsenic, cadmium, magnesium, mercury and selenium are not primarily associated with terrigenous sediments and their concentrations in sediments are unlikely to have been significantly influenced by Fly River discharge. Cadmium is primarily associated with coarse-grained carbonates of marine origin.

4. Six species (*T. crocea*, *T. maxima*, *P. margaritifera*, *P. erosa*, *T. niloticus* and *L. carponotatus*) are identified as good indicators of trace metal bio-availability on the basis that they do not appear to regulate the concentrations of most metals in their tissues.

However, only two (*T. crocea* and *P. erosa*) are recommended for use as bio-monitors in the main study as the others were found to have low abundance and a patchy distribution.

5. Seasonal differences in metal concentrations were not consistent across all locations that were sampled for biota. Two patterns are apparent: (a) in the central Torres Strait most trace metals showed little seasonal variation or elevated concentrations during the pre-monsoon season; while (b) in the northern Torres Strait many trace metals displayed higher concentrations during the post-monsoon season. Spatial patterns in trace metal concentrations were still more complex. However, many metals displayed highest concentrations at the most northern locations closest to the Papua New Guinea coast and Fly River, particularly during the post-monsoon season. Increases in the concentrations of cadmium, copper, strontium and zinc in *T. crocea* over the monsoon period appear to be related to coastal runoff and to have resulted from: (1) increased concentrations of these metals derived from river discharge; and/or (2) physico-chemical changes in the watermass leading to increases in (a) the bio-available portion of the metals only and/or (b) metal kinetics within biota. Changes in the concentrations of aluminium, arsenic, cobalt, mercury, nickel, lead, selenium and uranium over the monsoon period are thought to be unrelated to coastal runoff.

6. Concentrations of cadmium, copper, mercury, nickel, lead and zinc from various tissues within *T. crocea, T. maxima, P. margaritifera, H. hyotis* and *L. carponotatus* are contrasted with results from other published studies of these species from the Torres Strait, Great Barrier Reef and Coral Sea. On this basis, copper, mercury, nickel, lead and zinc concentrations in the central Torres Strait do not appear to be elevated above concentrations found elsewhere within the Great Barrier Reef. Only cadmium in samples from throughout the Torres Strait is elevated above background concentrations in the Great Barrier Reef. Copper appears to be elevated during the post-monsoon season at the most northerly sampling location only, but only to a level slightly above that found at coastal locations in the Great Barrier Reef. On the basis of biological concentration factors for *T. crocea*, only dissolved cadmium concentration appears to be very high in the Torres Strait.

7. Samples of *P. erosa* collected from Boigu and Saibai Islands identify seasonal differences in the concentration of only two metals, copper and mercury, both of which were elevated following the monsoon period. The relatively high concentrations of many metals from sampling locations on the Papua New Guinea mainland suggests that there may be a strong off-shore gradient which could potentially be confounded with any long-shore gradient. The marked differences in concentrations of many metals between the two mainland locations, which are separated by only a few kilometres, also suggest that inputs from rivers entering along the coast to the west of the Fly estuary may have a significant influence over local metal concentrations. This is consistent with Al-normalized trace metal concentrations in sediments which indicate that there is a major source of trace metals on the western side of the Torres Strait, possibly in Irian Jaya or along the west coast of Cape York peninsula.

8. The concentrations of arsenic, cadmium, copper, selenium and zinc in the edible portion (particularly in liver and kidney tissues) of some foods consumed by Torres Strait Islanders repeatedly appear at levels close to or above the National Health and Medical Research Council's Maximum Permitted Concentrations for seafoods. These foods include the Murray Island sardine *Harengula ovalis* (Ari Ari), the sardine/hardyhead (Kos), the green turtle *Chelonia mydas* (Waru) and the dugong *Dugong dugon* (Dhangal), all of which are reported to be important components of the diet of many Torres Strait Islanders. The metals arsenic, cadmium and selenium are not believed to be associated with Fly River discharge to any appreciable degree but copper may be. Similar high levels of these metals have been found in dugong liver and kidney tissues from other parts of the Great Barrier Reef in previous studies. These results should not be taken to signify an immediate health threat to Torres Strait Islanders who consume these foods. However, they do indicate the need for a more detailed study of the diet of Torres Strait Islanders and coastal Papuans, and the metal concentrations associated with the foods that are consumed.

9. The following recommendations are made:

(1) The arrangement and number of sampling stations should be modified from that originally proposed and be as indicated in Figures 93 and 94 for sediments and biota respectively. The western leg of the sediment transect which parallels the PNG coast should be moved closer inshore (see Fig. 93) so that variation in grain-size among locations is minimized. The station size for sediment sampling should be increased to 500m x 500m to avoid pseudo-replication of sites;

(2) Sampling of both sediments and biota as indicator organisms for the main study should be carried out during two periods: the pre-monsoon (October-November) and monsoon (February-March) seasons;

(3) The boring clam *Tridacna crocea* and the mangrove cockle *Polymesoda erosa* should be selected as indicator species for the main study. The shell length of *T. crocea* should be restricted to a size range of 70 to 80 mm. An alternative to shell length should be investigated as a measure of age (e.g. growth rings and shell weight);

(4) *T. crocea* should be collected along three transects from the following locations: Kokope Reef, Warrior Reef, Dungeness Reef, Poll Island, Campbell Island, Rennel Island, Aureed Island, Toms Son Bank, Bramble Cay, Underdown Reef, Little Mary Reef and Hibernia Passage reef. Five replicate samples should be collected from each of eight sites per location. Both replicates and sites should be randomly selected;

(5) *P. erosa* should be collected along three transects from the following locations: Boigu Island, Saibai Island, Bobo Island, Kussa Island, Warukuik, West Aberemuba, Zaigai Island and Sassie Island. Five replicate samples should be collected from each of three sites per location. Both replicates and sites should be randomly selected. Specimens should be flushed with double de-ionized water to remove any sediment adhering to the surface of the soft tissue or within the gut.

(6) The community fishery collection programme should continue. As a result of the paucity of samples from some locations, the small sample sizes and the relatively high concentrations of some metals in many species, collection should place an emphasis on:

(a) locations where few samples have been collected to date (e.g. Boigu and Saibai Islands); and

(b) those species which show relatively high concentrations of metals (e.g. *Agrioposphyraena barracuda*, *Choerodon schoenleinii*, *Epinephelus fasciatus*, *Harengula ovalis*, the sardine/hardyhead, *Chelonia mydas* and *Dugong dugon*);

(7) Consideration should be given to establishing a 'market basket' survey (of the type referred to in NHMRC, 1991) of the trace metal levels in the foods which constitute a significant part of the normal Torres Strait Islander diet. Representative communities from the different regions of the Torres Strait should be selected; and

(8) Future chemical analysis of samples should include tin (Sn) and establish the levels of inorganic arsenic. The concentrations of both of these metals are unknown at present, yet they are important in assessing the health implications of metals in diets. Consideration should be given to reanalysing samples from the present study which show high levels of total arsenic, for inorganic arsenic concentrations and tin, where sufficient material remains.

CONTENTS

INTRODUCTION

The Torres Strait Baseline Study (TSBS) was instigated in response to concerns by Torres Strait Islanders, scientists and conservationists about possible heavy metal contamination within the Torres Strait (see Lawrence & Dight, 1991 for background to the study). This concern arose as a result of mining activities within the Fly River catchment of Papua New Guinea. The purpose of the study is to acquire data that will assist in determining the extent of influence of Fly River discharge and whether there is evidence of elevated metal concentrations within the Torres Strait.

The TSBS has four component programmes: community fisheries, commercial fisheries, sediment and biota; the last two programmes constitute the scientific programme. The scientific programme objectives, conceptual design and details of the pilot study are reported by Dight (1991). A principal aim of the programme is to establish the spatial extent of trace metal inputs resulting from Fly River discharge. In light of this aim, the study design will seek to identify a gradient of change in trace metal concentrations away from the mouth of the Fly River. As such, the sampling programme will be carried out along a series of transects radiating away from the mouth of the Fly River. The transects lie along transport pathways into the Torres Strait.

A pilot study was instigated on the basis that: (1) there was a very poor understanding of spatial and seasonal variation in trace metals within the Torres Strait; (2) the complexity of the environment and the likelihood that trace metals would not be distributed and deposited uniformly throughout the region; (3) the distribution and abundance of suitable indicator organisms was largely unknown; and (4) there were no suitable estimates of variance in trace metal concentrations on which to base a sampling strategy which would ensure that environmental differences could be detected. This approach is considered fundamental as a first step in baseline and monitoring studies (Gordon et al., 1980).

The pilot study objectives therefore included: (1) the identification of species which would be suitable <u>indicators of trace metal bio-availability</u>; (2) the <u>development of sampling strategies</u> for selected metals in biota and sediments; (3) a preliminary assessment of <u>spatial and temporal variation in trace metal concentrations in sediments and biota</u> from the Torres Strait; and (4) an assessment of the impacts of current levels of <u>trace metals in marine biota on the health of Torres Strait Islanders and coastal Papuans</u>. This report will present results which are of relevance to these four objectives.

Indicators of Trace Metal Bio-availability

Phillips (1980) identifies a number of prerequisites for the selection of species as indicators of trace metal bio-availability. These include:

(1) Bio-monitors should be sessile or sedentary, thus being representative of a location, be abundant throughout the study area, easy to identify and sample, and provide sufficient tissue for analysis of the contaminants of interest;

(2) Bio-monitors should be hardy, accumulate the trace metals of interest, tolerate high levels of these metals and be suitable for laboratory studies of pollutant kinetics; and

(3) A simple relationship should exist between the pollutant concentration found in the tissues of a bio-monitor and the average ambient pollutant concentration. This relationship should be the same at all study sites.

The usefulness of bivalve molluscs as indicators of trace metal bio-availability is well established (Phillips, 1980; Phillips & Segar, 1986). This is reflected in the many studies of anthropogenic sources of trace metal contamination in the marine environment using mussels, oysters and other bivalve molluscs (e.g. Harris et al., 1979; Peerzada & Dickinson, 1989; Talbot, 1985,1986; Talbot & Chegwidden, 1982; Ward et al., 1986 in the Australian context). Possibly equally numerous are experimental studies, in both the laboratory and field, concerned with the uptake and behaviour of trace metals in bivalve molluscs (e.g. Behrens & Duedall, 1981; Elliot et al., 1985; Coleman et al., 1986).

Several of the species that were collected as part of the pilot study have been surveyed previously for trace metal concentrations within the Great Barrier Reef (GBR) and Torres Strait (Burdon-Jones & Denton, 1984a,b; Denton & Heitz, 1991). These include the bivalve molluscs *Tridacna crocea*, *Tridacna maxima*, *Pinctata margaritifera* and *Hyotissa hyotis*, and the reef fish *Lutjanus carponotatus*. On the basis of field surveys and trace metal determinations in various tissues, the kidney of both *T. crocea* and *T. maxima* and the liver of *L. carponotatus* were identified as the most suitable tissues for metal analysis because they concentrate many metals to well above background levels and showed greatest inter-location variability which appeared to reflect differences in environmental concentrations (Burdon-Jones & Denton, 1984a,b).

The uptake and depuration kinetics of cadmium, copper, lead, mercury and zinc in *T. crocea* have been studied experimentally in both the field and laboratory (Denton &

Heitz, 1991). All five metals are reported to obey the first-order kinetics model, indicating that there is little or no metabolic regulation and that renal accumulation rates are directly proportional to environmental concentrations. Such an understanding of metal kinetics provides an opportunity to predict time-averaged, bioavailable concentrations in the water column. However, Denton and Heitz (1991) point out that episodic inputs of elevated trace metal concentrations coupled with the inability of the biomonitor to attain equilibrium can be a major shortcoming with respect to the estimation of environmental concentrations from biological concentration factors.

Potential sources of variation in metal concentrations in bivalves, and clams in particular, have been identified as temperature, salinity, season, sex, reproductive status, physiological activity, diet, age, growth rate and the genetic make-up of individuals (Phillips, 1980; Denton & Heitz, 1991). These all interact with environmental metal concentrations to affect the metal status of an organism (Phillips, 1980). While some sources of variation cannot be controlled (e.g. physiological activity, diet and the genetic make-up of individuals), others such as season, reproductive status, age and growth rates can be minimized by selective sampling.

Spatial and Temporal Variation in Trace Metal Concentrations in Sediments and Biota

Three methods are commonly used to quantify trace metal concentrations: the analysis of water, sediments and biota. Phillips (1980) identifies several disadvantages associated with the use of water analysis as an indicator of trace metal availability. In particular, he draws our attention to the difficulty of producing a time-integrated value of pollutant concentration at any specific location and the low concentrations of some metals which can give rise to problems of analytical sensitivity and sample contamination. This is in contrast to the analysis of sediments and biota which provide time-integrated concentrations that are generally much higher than in water.

Metals associated with the inorganic particulate component of sediments are generally considered to have low bio-availability, while the analysis of total metal concentrations provides no information on how readily mobilized surface bound metals may be. In contrast, a strength of biota sampling is that the analysis provides a direct measure of trace metal bio-availability. However, different organisms have different accumulation characteristics and tolerances, and respond to different portions (dissolved, organic and inorganic particulate forms) of the total trace metal load. Thus, trace metal profiles in one species will not necessarily match those of another species in the same location at the same time. An assessment of seasonal variation in trace metal bio-availability is further complicated by variation in the uptake and depuration kinetics of trace metals as a consequence of reproduction and temperature/salinity changes in the water column.

In the Australian context, most studies have been conducted in temperate waters using species which are not present in the tropical waters of the Torres Strait. A notable exception is the extensive baseline survey of Burdon-Jones and Denton (1984a,b) which included algae, bivalve molluscs and fish from many locations within the Great Barrier Reef. This work provided a basis for the selection of potential indicator organisms and a reference with which to compare the concentrations of trace metals in selected biota from the Torres Strait.

Trace Metals in Marine Biota and the Health of Torres Strait Islanders and Papuans

All trace metals are found naturally in the environment and are incorporated to varying degrees into the tissues of all biota. However, while most also have known biological/metabolic functions, such as copper and iron in the transport of oxygen within the blood of crustaceans and fish respectively, others such as cadmium and mercury have no known biological function. In elevated concentrations and in large quantities, all trace metals (essential or not) become toxic and injurious to human health. The difference between levels that are beneficial and those that are harmful is sometimes small (WHO, 1973). Excessive metal intake is normally determined by comparison with Provisional Tolerable Weekly Intakes (PTWI) prepared by the Joint FAO/WHO Expert Committee on Food Additives. Maximum Permitted Concentration (MPC) refers to acceptable levels of metals in foods. It is set by individual nations and influenced by commercial trade considerations.

Broad-scale surveys of contaminants in foods, such as the Australian Market Basket Survey, are designed to monitor and assess the level of contaminants in 'typical' foods or diets, and in this way ensure that they do not cause concern from a public health point of view (NHMRC, 1991). However, population sub-groups who have unusual diets or consume large quantities of seafood are not well catered for in such surveys. Relatively little is known about the diet of Torres Strait Islanders and coastal Papuans and, in particular, how it varies from community to community. However, the importance of the marine resources to their diet is widely acknowledged (e.g. Fitzpatrick, 1991). Seafood consumption rates appear to be amongst the highest in the world (Johannes & MacFarlane, 1991) and include a very wide range of items, such as turtle, dugong, many species of reef and pelagic fish, molluscs and crustaceans (Nietschmann, 1984; Johannes & MacFarlane, 1991; Poiner & Harris, 1991).

MATERIALS AND METHODS

Sample Collection

The standard sampling procedure within each station, or location (note that station and location will be used interchangeably), was to randomly select three sites and to collect replicate samples from each site. The number of replicate samples varied between sediments and biota, between species and, sometimes, between locations and sites. Sample collection for sediments and biota as indicator organisms or species was conducted during two seasons in the Torres Strait: one at the end of the dry or trade-wind season (pre-monsoon) and the other following the monsoon season (post-monsoon).

Sediments

The sampling stations or locations from where sediment samples were collected are presented in Figure 1. The locations of sampling stations, in coordinates, were pre-determined and their positions identified on site using Global Positioning System (GPS) navigation. Each sampling station was represented by an area defined as a square placed centrally over the station coordinates. Each side of the square had a length of 200 metres. Sampling sites were similarly located using GPS navigation. Pre-monsoon sampling was carried out over the period 15-25 September, 1991 while post-monsoon sampling was carried out over the period 4-13 March, 1992.

Sediment samples were collected using a number of techniques. These included a specially modified Smith-McIntyre grab made from high grade stainless steel, polypropylene hand-corers and a gravity corer. The aim was to determine the most effective means of sampling sediments and ensuring that the fine surface material was not lost. The gravity corer proved not to be successful in the sometimes relatively shallow water and sediments of varying levels of consolidation, and its use was abandoned. Both grab and diver hand-core samples were collected from three locations (S10, S2 and S5). As sampling at a single station often required several hours, replicate samples were necessarily collected over sometimes quite considerable variation in current strength and direction. Station means therefore represent the integration of values over a significant portion of a flood-ebb tidal cycle. Two locations, S10 and S2, were sampled using both techniques on two occasions during the post-monsoon season

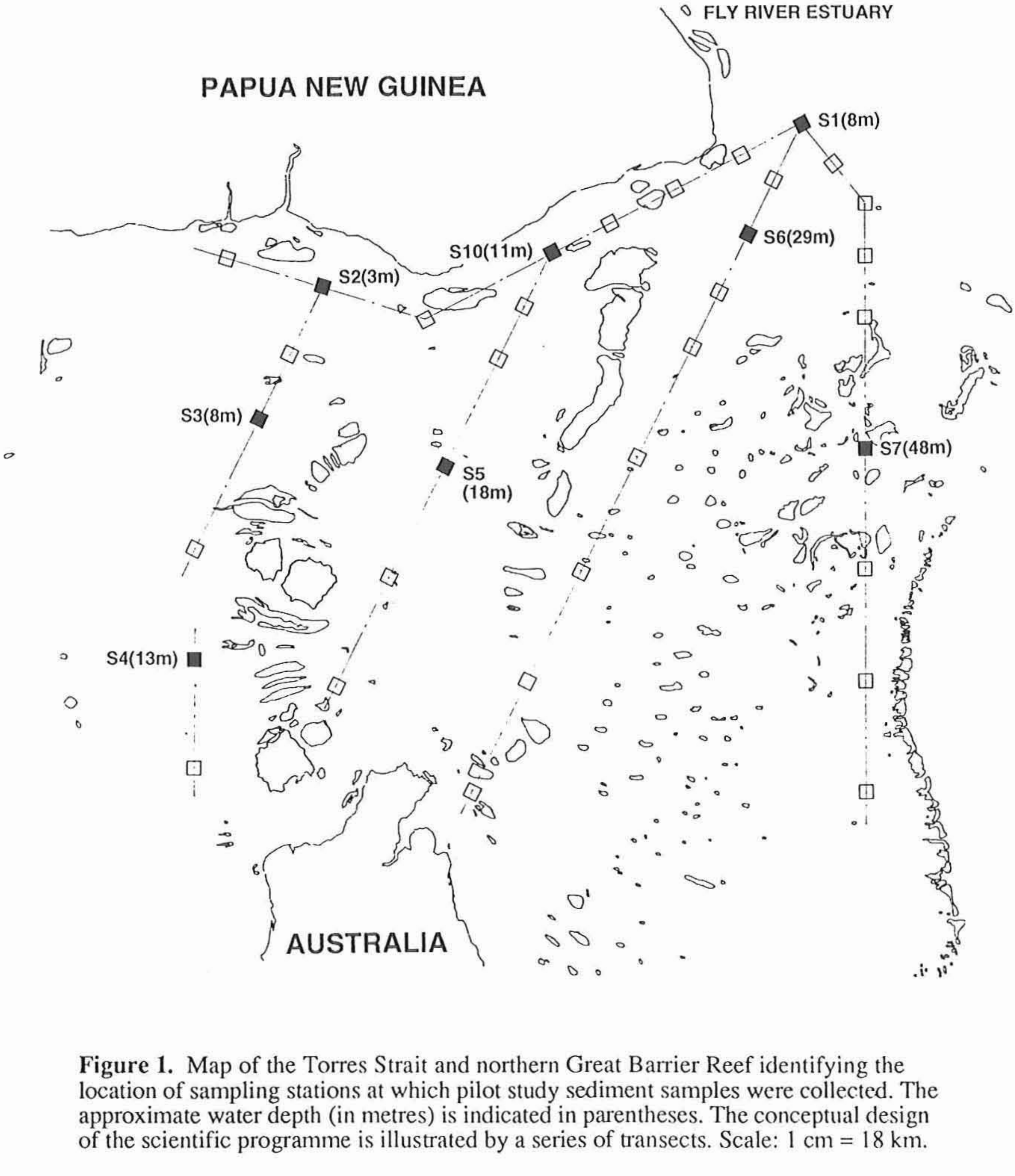


Figure 1. Map of the Torres Strait and northern Great Barrier Reef identifying the location of sampling stations at which pilot study sediment samples were collected. The approximate water depth (in metres) is indicated in parentheses. The conceptual design of the scientific programme is illustrated by a series of transects. Scale: 1 cm = 18 km.

separated by five and six days respectively. These samples therefore represent variation over a spring-neap tidal cycle. On one occasion, the sampling area of station S10 was also increased to 2000 x 2000 metres.

Laboratory protocols are detailed in Waite and Szymczak (1991). Excess water from the grab was allowed to drain before the sample was deposited on a plastic container. The sample was then transfered to a laminar flow hood where the surface sediment of each grab sample, to a depth of approximately 5 cm, was sub-sampled using the hand-corers. The sub-samples from each grab were then combined to give a single replicate sample. The hand-core samples were collected by divers using SCUBA equipment. Two hand-core samples of the surface 5 cm of sediment were combined within a laminar flow hood to provide a single replicate sample. All sediment samples were then stored in acid washed plastic containers and stored within a freezer on board the M.V. *Western Venturer*.

Biota

The sampling stations or locations from where biota as indicator species were collected are presented in Figure 2. No species were found at all sampling locations as the stations correspond to a wide range of quite different habitats, from coral reefs surrounded by clear oceanic waters to coastal mangroves. The locations of sampling stations were pre-determined only in a general sense (i.e. to the level of reef or island). Preliminary surveys of the biota indicated where individual species could be found (if at all) in relative abundance. Pre-monsoon sampling was carried out over the period 8-27 October, 1991 while post-monsoon sampling was carried out over the period 8 April to 1 May, 1992. A listing of the species and locations from where samples as indicator species were collected during the two seasons is presented in Table 1. Some samples were not analysed for this report because of either insufficient funds for analysis or because difficulties in collecting and processing made them unsuitable for future indicators (e.g. *Halophila ovalis*)

Raine Island samples were collected by the TSBS, for the Raine Island Corporation and the Queensland Department of Primary Industries. Data used in this report from these samples can be found in Barry and Rayment (1992).

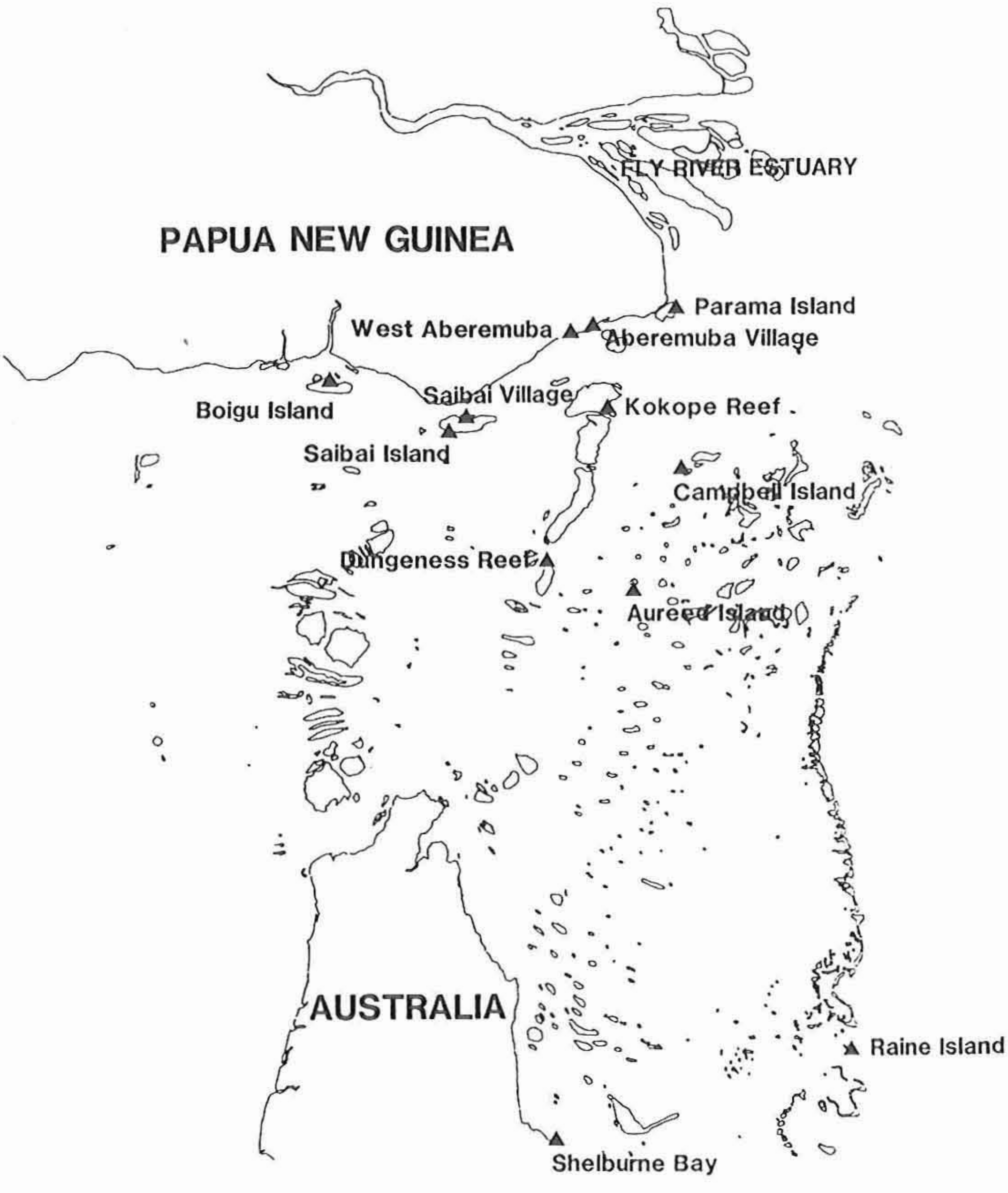


Figure 2. Map of the Torres Strait and northern Great Barrier Reef identifying the location of sampling stations at which pilot study indicator species were collected. Scale: 1 cm = 28 km.

Table 1. Listing of the species and locations from where samples as indicator species were collected during the pre- and post-monsoon seasons.

Species	Location (pre-monsoon)	Location (post-monsoon)
Thalassia hemprichii	Campbell Is, Dungeness Rf	Campbell Is, Dungeness Rf, Kokope Rf, Aureed Is
Thalassodendron ciliatum	Dungeness Rf, Kokope Rf	Dungeness Rf, Kokope Rf
Tridacna crocea	Aureed Is, Campbell Is,Dungeness Rf, Kokope Rf	Aureed Is, Campbell Is, Dungeness Rf, Kokope Rf
Tridacna maxima	Campbell Is, Raine Is	Aureed Is, Campbell Is
Pinctata margaritifera	Aureed Is, Campbell Is	Aureed Is, Kokope Rf, Campbell Is, Dungeness Rf
Hyotissa hyotis	Aureed Is, Kokope Rf	Aureed Is, Kokope Rf, Campbell Is, Dungeness Rf
Chama plinthota	Aureed Is,	Aureed Is, Kokope Rf, Campbell Is, Dungeness Rf
Trochus niloticus	Aureed Is, Dungeness Rf Kokope Rf, Raine Is	Aureed Is, Kokope Rf, Campbell Is, Dungeness Rf
Strombus luhuanus	Aureed Is, Campbell Is	Aureed Is, Campbell Is
Stichopus chloronotus	Aureed Is, Kokope Rf	Aureed Is, Kokope Rf, Campbell Is, Dungeness Rf
Lutjanus carponotatus	Aureed Is	Aureed Is, Kokope Rf, Campbell Is, Dungeness Rf
Polymesoda erosa	Boigu Is, Saibai Is, Shelburne Bay	Boigu Is, Saibai Is, Parama Is,West Aberemuba, Aberemuba Village
Halophila ovalis		Kokope Rf, Dungeness Rf

The bivalve molluscs *T. crocea*, *T. maxima*, *P. margaritifera*, *H. hyotis* and *C. plinthota* all burrow into or are firmly attached to the reef substratum and mostly needed to be dislodged using a hammer and chisel. The soft tissue of each of these species is protected by shell and was not damaged or touched in any way during the removal process. The reef fish *L. carponotatus* was collected either by line fishing (pre-monsoon sampling) or spearfishing (post-monsoon sampling). In the latter case, the stainless steel spears and tips were cleaned regularly with nitric acid and any rust removed. Fish were speared such that the viscera, eye/otolith area or tail muscle were not damaged. All other species were collected without resort to the use of metal collection devices.

Individual specimens were immediately washed in clean seawater to remove surface material, double bagged, labelled and stored in insulated containers with sealed plastic ice bricks. On return to the research vessel (M.V. *Western Venturer* or R.V. *Sunbird*) the shells were scrubbed in de-ionized water with a nylon brush, measured with plastic callipers, individually double bagged and labelled. Only samples of *Polymesoda erosa* were frozen while the remaining species samples were maintained at approximately $4^{o}C$. Laboratory protocols are detailed in Rayment and Murphy (1991).

The sampling stations or locations from where biota as community fishery samples were collected are presented in Figure 3. A listing of the scientific, common and Islander names of the species collected is presented in Table 2. Samples were collected by community members using normal fishing techniques over a period of nine months from June, 1991. Samples were subsequently washed in clean seawater, double bagged, labelled and frozen. In most cases the fishes were eviscerated before being bagged.

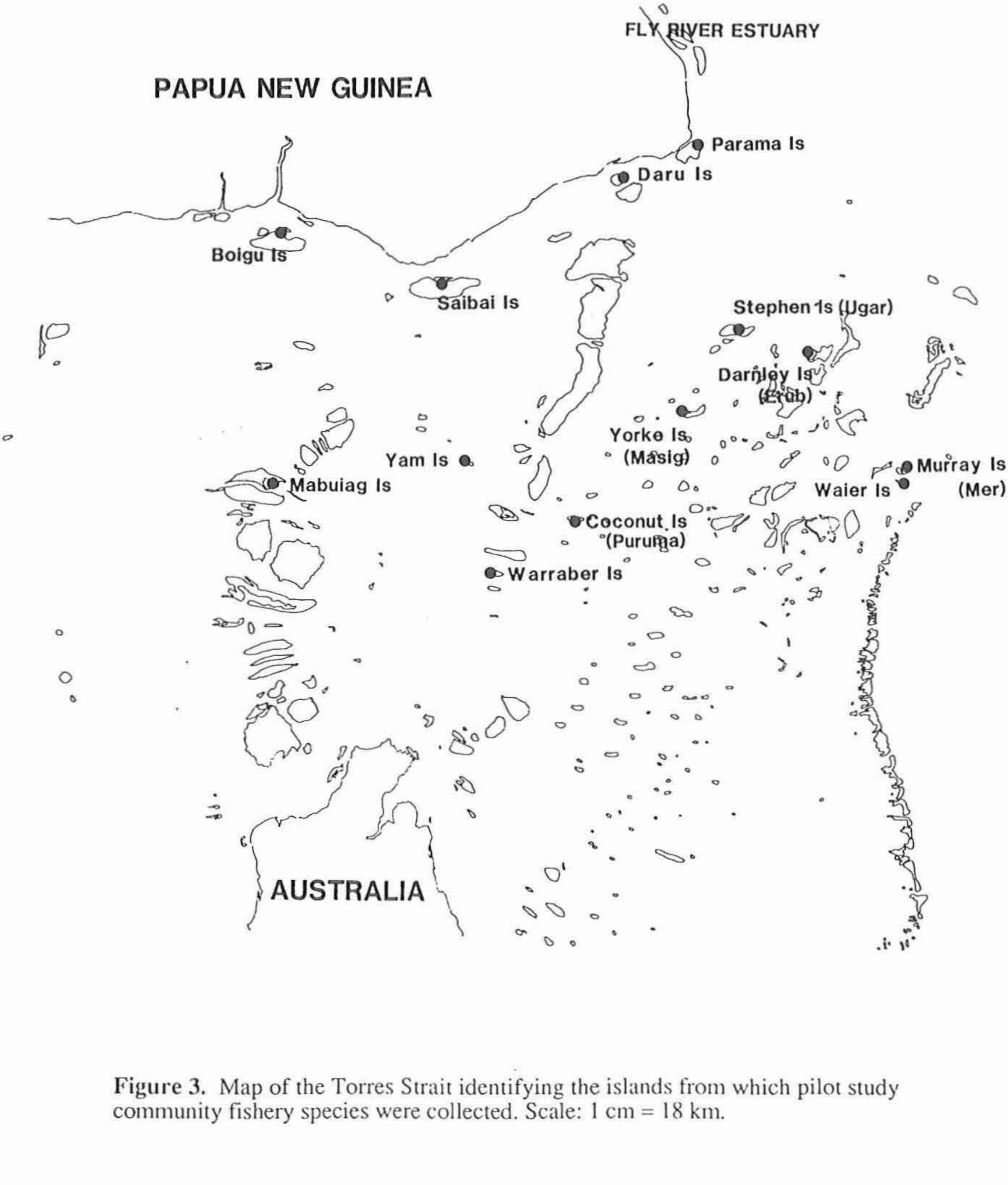


Figure 3. Map of the Torres Strait identifying the islands from which pilot study community fishery species were collected. Scale: 1 cm = 18 km.

Table 2. Listing of the species collected for the community fishery component.

Scientific name	Common name	Islander name
Fishes		
Agrioposphyraena barracuda	Barracuda	?
Carangoides fulvogutus	Gold spotted trevally	Duger
Choerodon schoenleinii	Black spot tusk fish	Woona
Epinephelus fasciatus	Footballer cod	?
Epinephelus quoyanus	Longfin rockcod	Garom
Harengula ovalis	Murray Is. sardine	Ari Ari
?	Sardine / hardyhead	Kos
Lates calcarifer	Barramundi	Barramundi
Lethrinus fletus	Grass sweetlip	Snapper
Lutjanus carponotatus	Stripey	Theur, Kauerr, Tanab
Plectropomus leopardus	Coral trout	Withi
Plectropomus maculatus	Barred-cheek coral trout	Withi
Plectorhynchus flavomaculatus	Netted sweetlip	?
Plectorhynchus pictus	Morwong	Peku, Wapa fish
Psammoperca waigiensis	Reef barramundi	Night fish
Scomberomorus commerson	Spanish mackerel	Dubui
Siganus guttatus	Golden lined spinefoot	Erar, Parrsa
Siganus spinus	Black spinefoot	Kibim
Crustaceans		
Panuliris ornatus	Painted crayfish	Kaiar
Panuliris versicolor	Crayfish	Kaiar
Molluscs		
Hippopus hippopus	Horse's hoof clam	Clam shell (?)
Lambis lambis	Spider shell	Arsoorr
Polymesoda erosa	Mangrove cockle	Akul, Eepa
Strombus luhuanus	Red-lipped stromb	Kirith
Other		
Chelonia mydas	Green turtle	Waru
Dugong dugon	Dugong	Dhangal

Sample Preparation

Sediments

The frozen samples were transported to a selected analytical laboratory where two representative portions of each sample were separated. One portion was wet sieved and separated into >2 mm, 2000-200 μm, 200-63 μm and <63 μm size fractions. The >2 mm size fraction was removed by wet sieving from the second portion before being dried at 50°C in a stainless steel forced draft oven. Removal of the >2 mm size fraction was achieved using plastic sieves and sea water (pre-monsoon samples) or ultra pure water (post-monsoon samples). In the latter case, the washings were evaporated and included in the <2 mm portion. Samples were subsequently ground to <50 μm particle size using a 'shatter box' grinding mill equipped with a stabilized zirconium grinding head and stored in dry, sealed acid washed plastic containers.

Biota

All biota were transported to the Horn Island Research Station where the initial sample preparation took place. Cleanroom conditions were adhered to and all dissections took place within a certified laminar-flow hood. Dissections were performed using high quality stainless steel instruments on acid washed polypropylene cutting boards. The tissue samples were then placed in acid washed plastic vials, labelled, frozen and transported to Brisbane for freeze-drying and storage prior to analysis.

Leaf material, including a minimal amount of epiphytic algae, constituted the sample for seagrasses. The inclusion of some epiphytic algae was unavoidable in spite of the field collection team members' attempts to avoid plants which were heavily fouled. The kidney of *T. crocea* and *T. maxima* constituted the primary sample, although the adductor muscle and visceral mass were also removed. The Tridacnid clams, in particular, were maintained in a fresh condition in order to avoid contamination of other tissues by the metal-rich kidney during or after freezing. Body muscle tissue constituted the sample for the gastropod molluscs *T. niloticus* and *S. luhuanus*, while muscle tissue was also taken from the tail of the reef fish *L. carponotatus*. However, the liver provided the primary sample for *L. carponotatus*. The whole soft tissue constituted the prepared sample from *P. margaritifera*, *H. hyotis*, *C. plinthota* and *P. erosa*.

Chemical Analysis

Sediments

Dried sediment samples were analysed for a suite of major and trace elements, as well as calcium carbonate and organic carbon content. Samples for aluminium (Al), calcium (Ca), chromium (Cr), iron (Fe), magnesium (Mg), manganese (Mn), nickel (Ni), silica (Si) and zinc (Zn) determination were pelleted using the pressed powder technique and analysed by X-ray fluorescence. Samples for arsenic (As) and selenium (Se) determination were digested using nitric:perchloric:sulphuric acid (13:1:1) and analysed by hydride generation ICP. Mercury (Hg) determination was also by hydride generation ICP while the digestion/extraction procedure involved nitric:hydrochloric acid (6:2) in a 2 hour steam bath. Cadmium (Cd) and lead (Pb) determinations involved a nitric:hydrochloric acid (6:2) digest in a 2 hour steam bath and analysis by graphite furnace AAS, while cobalt (Co) and copper (Cu) determinations involved a nitric:perchloric:sulphuric acid (13:1:1) digest and analysis by Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES). Standard reference material (BCSS1 - marine sediment) was routinely analysed together with sediment samples and the results maintained within certified values.

Biota

Chemical analysis of most samples was carried out using Inductively Coupled Plasma Mass Spectrometry (ICP-MS) for aluminium (Al), arsenic (As), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), mercury (Hg), manganese (Mn), nickel (Ni), lead (Pb), selenium (Se) and zinc (Zn) concentrations in the tissues of all samples. The concentrations of silver (Ag), strontium (Sr) and uranium (U) were also determined within the kidney of *T. crocea* and the post-monsoon samples of kidney from *T. maxima*. The freeze-dried sample (approx. 0.2 g) was microwave digested using double distilled nitric acid (HNO_3) prior to chemical analysis. Flame and graphite furnace atomic absorption spectrometers (Varian) or ICP-AES were used for *P. margaritifera* samples, but otherwise mainly for some quality assurance samples. The FSIS system for reporting concentration results has been adopted. Standard reference material (DORM-1 - dogfish muscle and TORT-1 - lobster hepatopancreas) was routinely analysed together with biota samples and the results maintained within certified values.

Quality Assurance

All possible precautions were taken in the field and during preparation to avoid contamination of samples. Neoprene diving gloves were worn during collection, while plastic surgical gloves were used to handle any material that was to be analysed directly, or was likely to be taken into the clean room facility on Horn Island, or come in contact with material that was to be analysed. All collecting and measuring equipment was acid washed in 10% nitric acid and thoroughly rinsed with de-ionized water. Sub-samples of the plastic bags that were used had been tested for metal concentrations to ensure that they would not be a source of contamination.

Participating laboratories all took part in the 1991 and 1992 U.S. National Oceanic and Atmospheric Administration (NOAA) National Status and Trends Quality Assurance Programme. Within that programme, the laboratories demonstrated that they had the ability to produce accurate and repeatable analytical results for a wide range of trace metals. The analysis and reporting of results from standard reference materials was carried out on a regular basis. In addition, approximately 10% of samples were sub-sampled and sent to a second and sometimes third laboratory to ensure that the results were reliable. These results (not presented) showed good agreement.

Statistical Analyses

Preliminary analysis of the data showed that the variances were not always homogeneous. A natural logarithmic transformation was therefore applied to all concentration data ($\log_e$(concentration+1)) prior to statistical analysis to ensure that the variances were made homogeneous and normally distributed.

A nested (hierarchical) Analysis of Variance (ANOVA) was used to assess differences in metal concentrations among locations (sampling stations) for the three indicator species. Where significant differences existed among three or more locations from where samples were collected, Tukey's HSD test was used to determine which sampling stations were different from each other.

The concentrations of some metals (e.g. Cd and Hg) in certain samples were, on occasions, found to be below the analytical detection limit. In this situation, use of the detection limit for the actual concentration would clearly bias the results upward. A more realistic approach, and one which has been widely adopted (e.g. Burdon-Jones & Denton, 1984a; Ward et al., 1986; NHMRC, 1991), is to assume that the actual value lies midway between the detection limit and zero. It is this approach which was taken for the present data analyses.

Normalization procedures

Many trace metals are primarily associated with particle surfaces and differences in concentrations between locations, or even sites within locations, may result simply from differences in the particle size distribution of the sediment samples. Two approaches to the normalization of trace metals in sediments are frequently used: granulometric and geochemical methods. Both are investigated in this study. NOAA (1988) used the former method and normalized concentration data by dividing the raw concentration by the fraction by weight of sediment particles (from the same location) less than 64 µm. NOAA note that this is equivalent to assuming that there are no trace metals associated with the coarser sediment size fractions. Clearly this is not strictly true and the method biases the concentrations upwards where the coarse fraction is very large. Consequently, NOAA do not use this method to compare locations where the sediment contains less than 20 percent fine-grained material.

Geochemical normalization is thought to be better than granulometric methods because it compensates for the mineralogical as well as granular variablility in trace metal concentrations in sediments (Loring, 1991). Aluminium concentration has been widely used as a geochemical method to normalize many, but not all, trace metal concentrations with respect to granular variability because it is a major constituent of the fine-grained aluminosilicates with which trace metals are associated in tropical waters (e.g. Windom et al., 1989; Loring, 1991; Din, 1992). This technique also suffers from a similar bias to the granulometric method where aluminium concentrations (i.e. the fine-grained sediment fraction) are very low, as the denominator is then small relative to the numerator. Loring (1991) identifies the following requirements for effective geochemical normalization: (1) significant granular variations should occur between sediment samples; (2) a statistically significant relationship should exist between (a) the normalizer and grain size distribution; and (b) metal content and the normalizing element; and (3) it should be possible to provide accurate and precise analysis of the metal of interest and normalizing element.

Power analysis

Of the metals for which concentration data are available, six have been selected as being of particular importance. These are arsenic (As), cadmium (Cd), copper (Cu), mercury

(Hg), selenium (Se) and zinc (Zn). Arsenic, cadmium and selenium were all found to be in high concentrations in a range of food items that are consumed by Torres Strait Islanders (Dight, 1992 and reported here), while copper, mercury and zinc are all known to be associated with Fly River discharge or mining operations within the catchment (Baker, 1991; Eagle & Higgins, 1991; Ross, 1991).

The power of the sampling program to detect a specified increase in metal concentration was derived from formulae provided by Cohen (1988) and Mapstone (pers. comm.) for medium variability of a range of means. For any particular trace metal, the range of means was the difference between the maximum and minimum mean value taken from the various sampling stations. Within population standard deviation was estimated from the sites Means Square value from the ANOVA results of the pilot study data. An adjusted n value (n') was calculated from the formula in Cohen (1988) for fixed main effects in factorial designs. Power estimates are based on a range of means for four sampling stations.

The selected number of sites for each species was based on the time taken to collect and process samples, and the likely availability of the species of interest. For example, it would be possible for two teams of three persons to collect and process samples of *T. crocea* from a maximum of eight sites in one day. A greater number of sites would also be likely to result in some overlap among sites.

RESULTS

Sediments

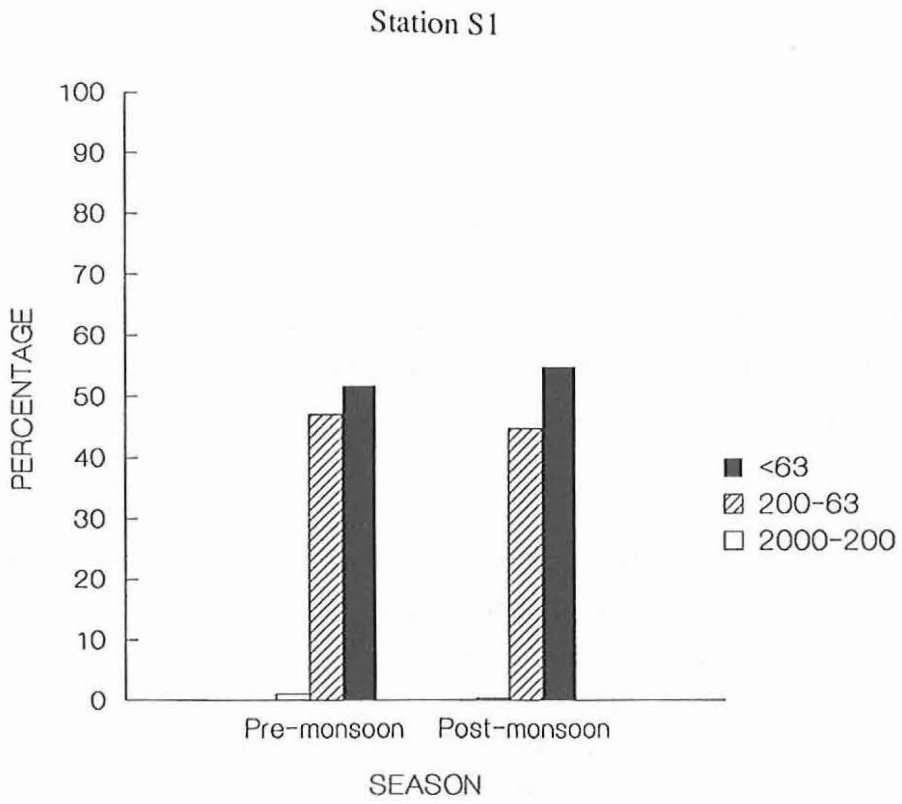
Physico-chemical characteristics

The particle size distributions of grab samples from each station during both sampling periods (pre- and post-monsoon) are contrasted in Figure 4. The calcium carbonate ($CaCO_3$) and organic carbon content of the same samples are presented in Figures 5 and 6 respectively.

Station S1 (Fig. 4), which lies within the Fly River delta, is markedly different from all other sampling stations in that the dominant particle size fraction (>50% by weight) is <63µm. The 200-63 µm size class is almost as large (approximately 46%), while the relatively coarse 2000-200 µm size fraction corresponds to less than 1% of the sample by weight. The post-monsoon samples displayed a slightly higher proportion of fines (<63 µm) with a corresponding loss from both the coarser size fractions. This station is also characterized by sediments with the lowest $CaCO_3$ content (approximately 1% - Fig. 5) and highest organic carbon content (approximately 1.5% - Fig. 6).

Sampling station S10 (Fig. 4), which lies along the PNG coast to the north-east of Saibai Island, is also unique in that the dominant particle size fraction (>70% by weight) is 200-63 µm. The <63 µm size class at this station contributed approximately 19% while the 2000-200 µm size fraction contributed only about 6% by weight. A slight increase in the proportion of fines (<63 µm), with a corresponding loss from the coarsest size fraction, is also evident at station S10 during the post-monsoon sampling period. This station is characterized by sediments with the second lowest $CaCO_3$ content (approximately 27% - Fig. 5) and second highest organic carbon content (approximately 1.1% - Fig. 6) during the post-monsoon sampling period (but not during the pre-monsoon period).

All the remaining sampling stations, S2, S3, S4, S5, S6 and S7 (Fig. 4) were dominated by the 2000-200 µm size fraction and characterized by sediments containing approximately 50% or greater $CaCO_3$. Stations S5 and S6 display higher proportions of the medium and fine sediment size fractions than S2, S3, S4 and S7. Station S6, which lies between the Fly River estuary and northern entrance to the Great North East Passage, is also characterized by sediments with proportionally lower



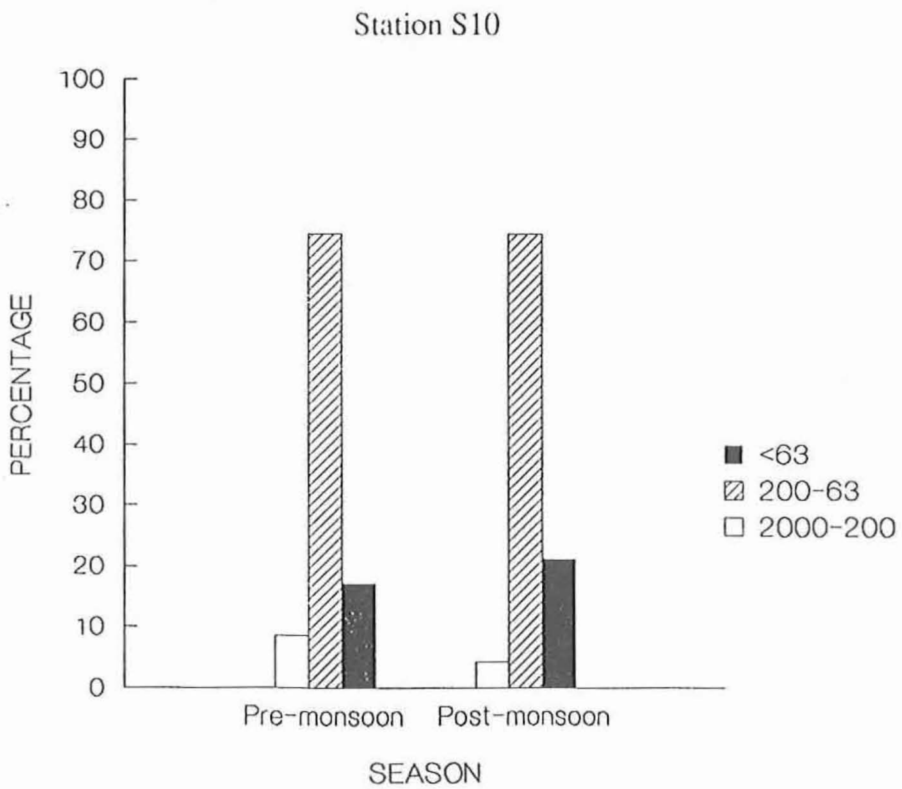
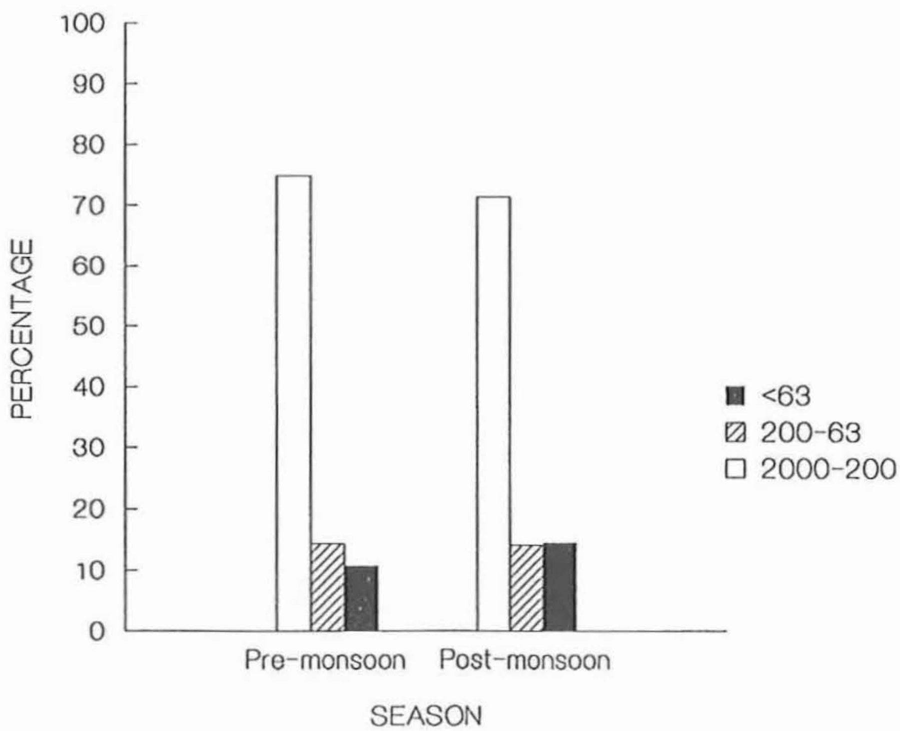


Figure 4. Particle size distribution as a percentage (by weight) of the <2 mm size fraction of sediment samples (collected using a Smith-MacIntyre grab) from all stations during two seasons. The size-class fractions are 2000-200 µm, 200-63 µm and <63 µm (cont. over).

Station S2



Station S3

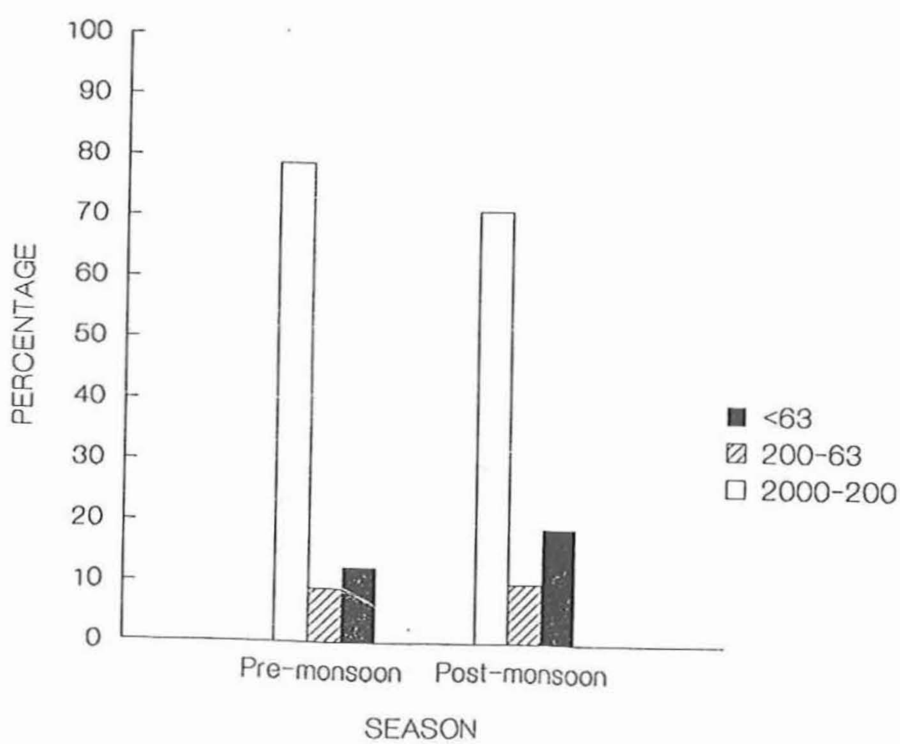
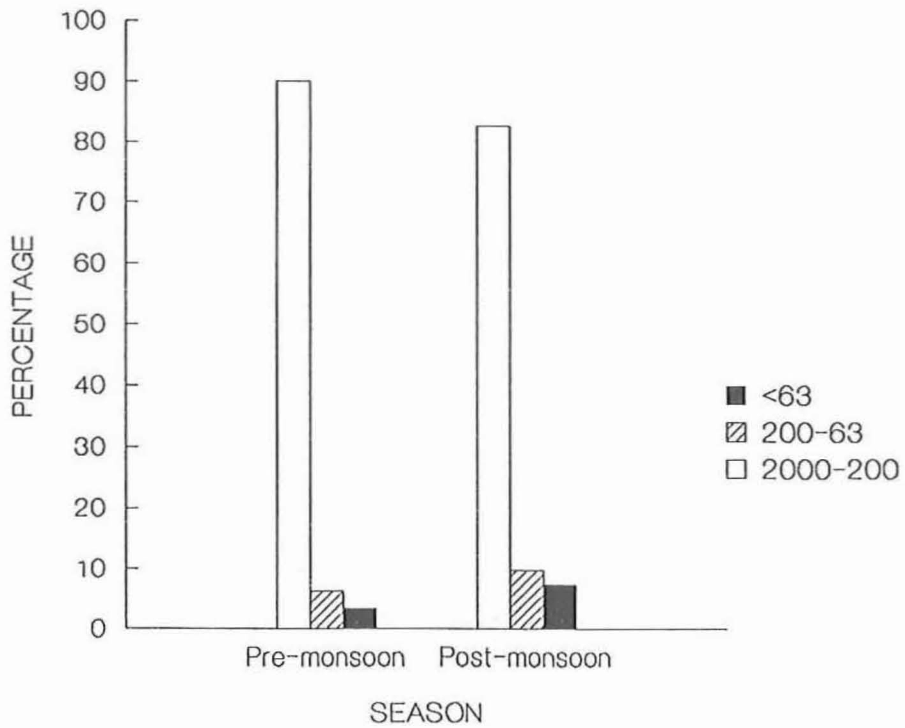


Figure 4. (cont.)

Station S4



Station S5

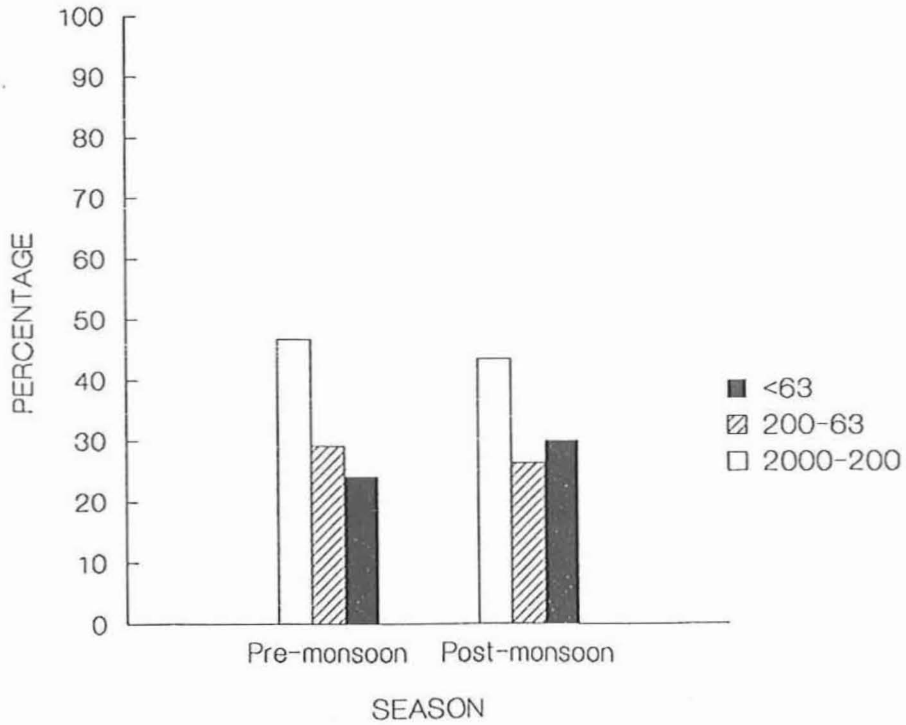
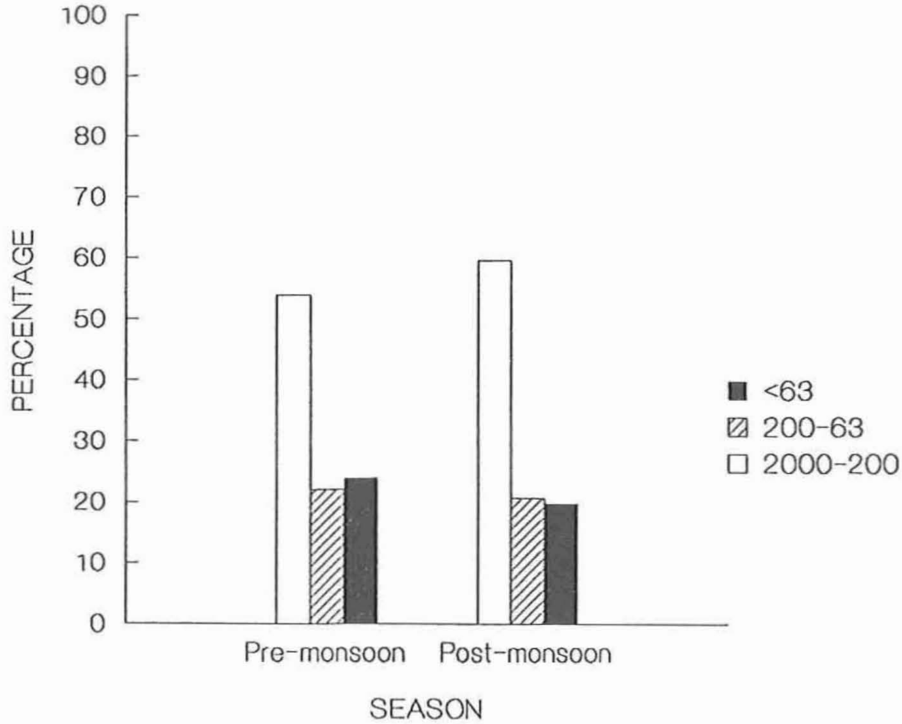


Figure 4. (cont.)

Station S6



Station S7

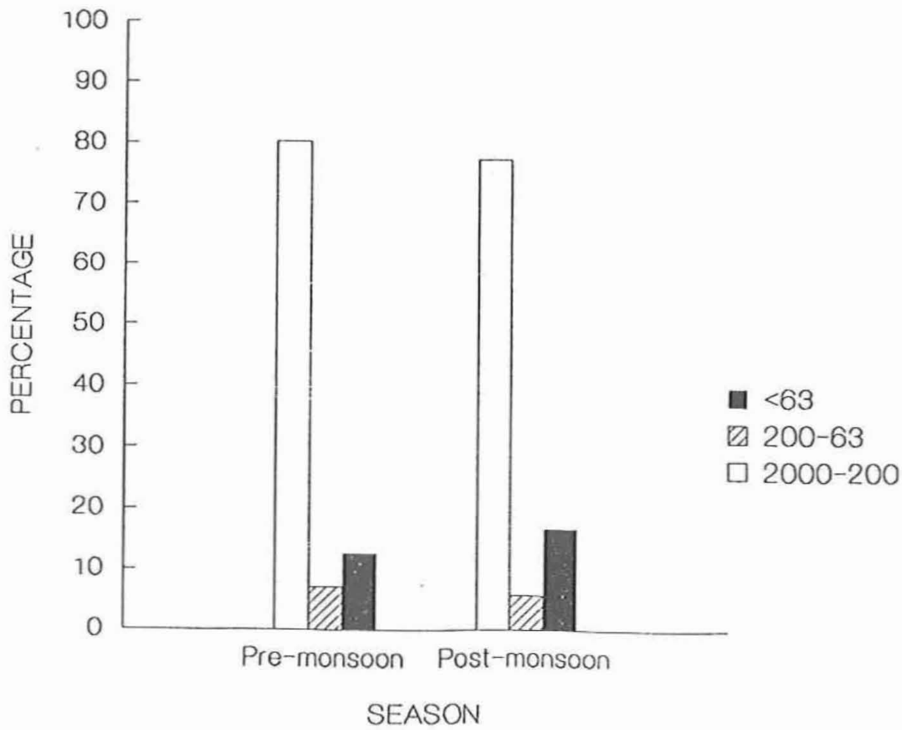
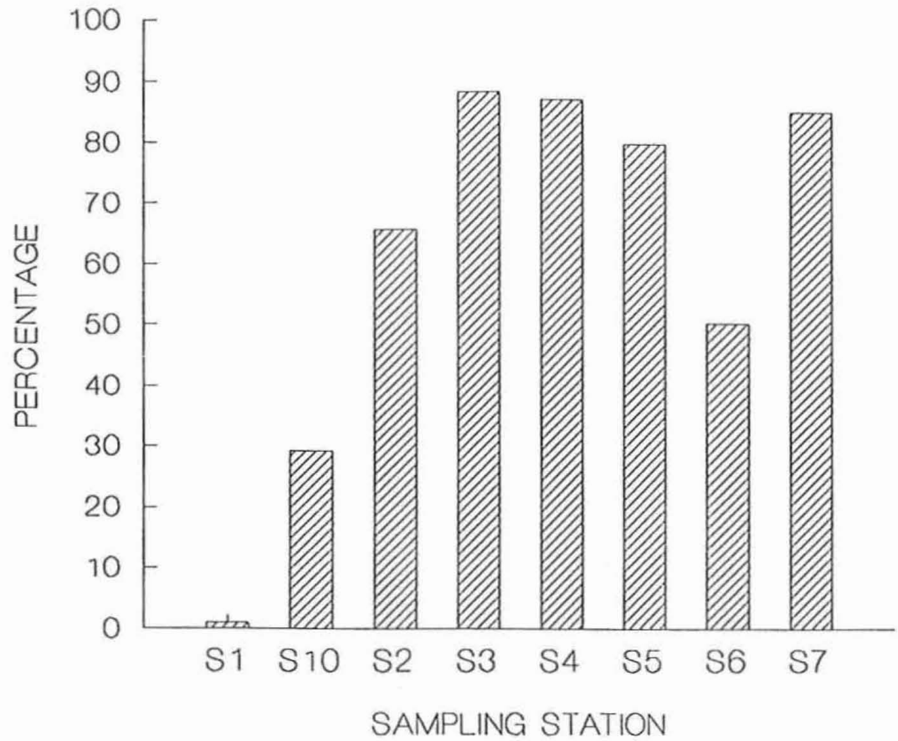


Figure 4. (cont.)

(a)



(b)

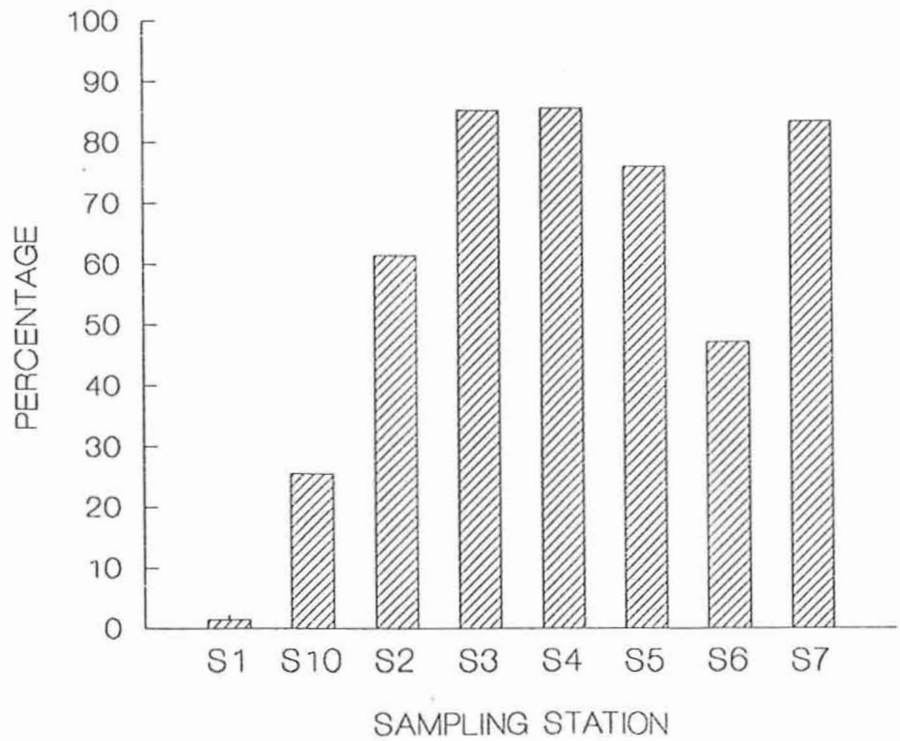
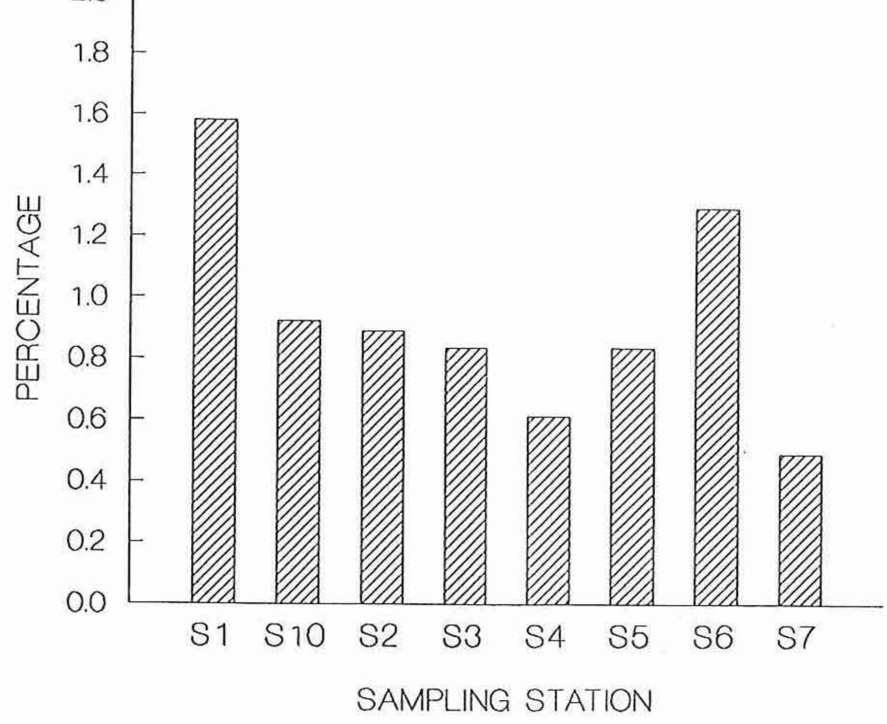


Figure 5. Calcium carbonate ($CaCO_3$) content as a percentage (by weight) of the <2 mm size fraction of sediment samples (collected using a Smith-MacIntyre grab) from all stations during (a) the pre-monsoon season and (b) the post-monsoon season.

(a)



(b)

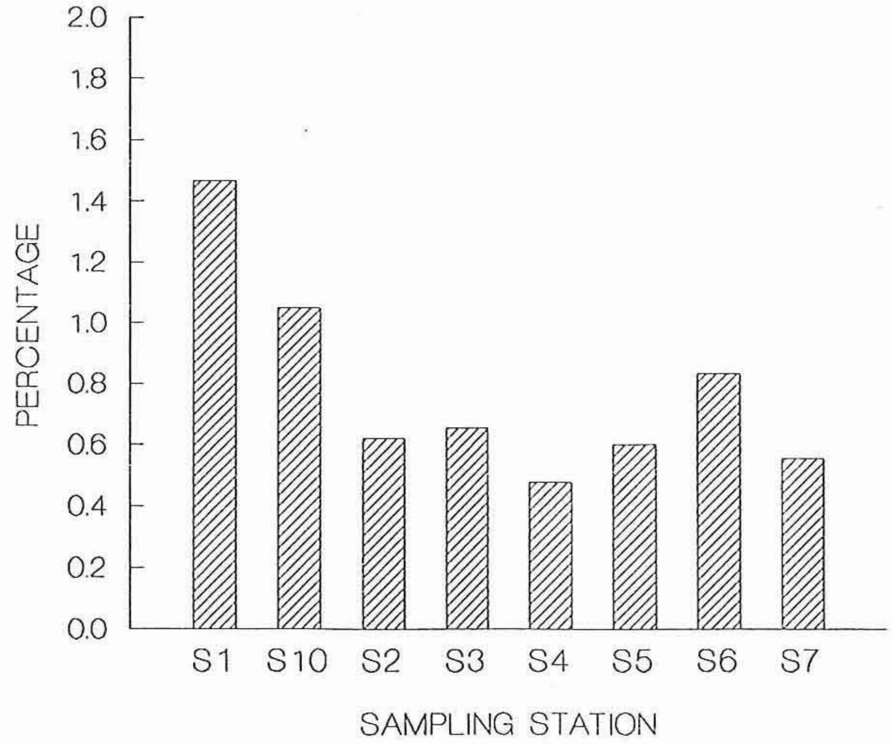


Figure 6. Organic carbon content as a percentage (by weight) of the <2 mm size fraction of sediment samples (collected using a Smith-MacIntyre grab) from all stations during (a) the pre-monsoon season and (b) the post-monsoon season.

$CaCO_3$ (approximately 49% - Fig. 5) and higher organic carbon content during the pre-monsoon period (approximately 1.3% - Fig. 6) than stations S2, S3, S4, S5 and S7. Only stations S1 and S10 (during the post-monsoon period) had sediments with higher organic carbon content.

The particle size distribution of diver (hand-core) and grab samples from stations S10, S2 and S5 during both sampling periods (pre- and post-monsoon) are contrasted in Figures 7 to 9 respectively. While the general particle size distributions do not vary markedly between methods, some differences are apparent. During the pre-monsoon period, diver samples from stations S10, S2 and S5 displayed proportionally more fines (<63 µm) while grab samples from stations S2 and S5 displayed proportionally more fines (<63 µm) during the post-monsoon period.

The particle size distributions of grab samples collected at two stages in the tidal cycle from stations S10 and S2 during the post-monsoon period are contrasted in Figure 10. Both display some differences in the proportion of fines (<63 µm) between sampling events 5 and 6 days apart for stations S10 and S2 respectively.

The particle size distributions of grab samples collected over two different station areas (sizes) from S10 during the post-monsoon period are contrasted in Figure 11. A major difference is evident in the particle size distribution as a consequence of increasing the sampling area of the station. In particular, the larger sampling area has resulted in a dramatic increase in the coarser grained material (2000-200 µm) with a corresponding loss from the 200-63 µm size fraction.

A Pearson correlation matrix between the sediment particle size fractions (2000-200 µm, 200-63 µm and <63 µm), $CaCO_3$ and organic carbon content, and the $\log_e$ metal concentration from all grab samples is presented in Table 3. All correlations except mercury (Hg) and the 200-63 µm size fraction and selenium (Se) and organic carbon are significantly different from zero ($p<0.05$). Calcium carbonate ($CaCO_3$) content in the sediments is positively correlated with the coarser size fraction (2000-200 µm) and negitavely correlated with the finer (200-63 and <63 µm) size fractions. Organic carbon, in contrast, is mostly associated with the finest sediment size fraction (<63 mm) and negatively correlated with the (predominantly $CaCO_3$) 2000-200 µm size class.

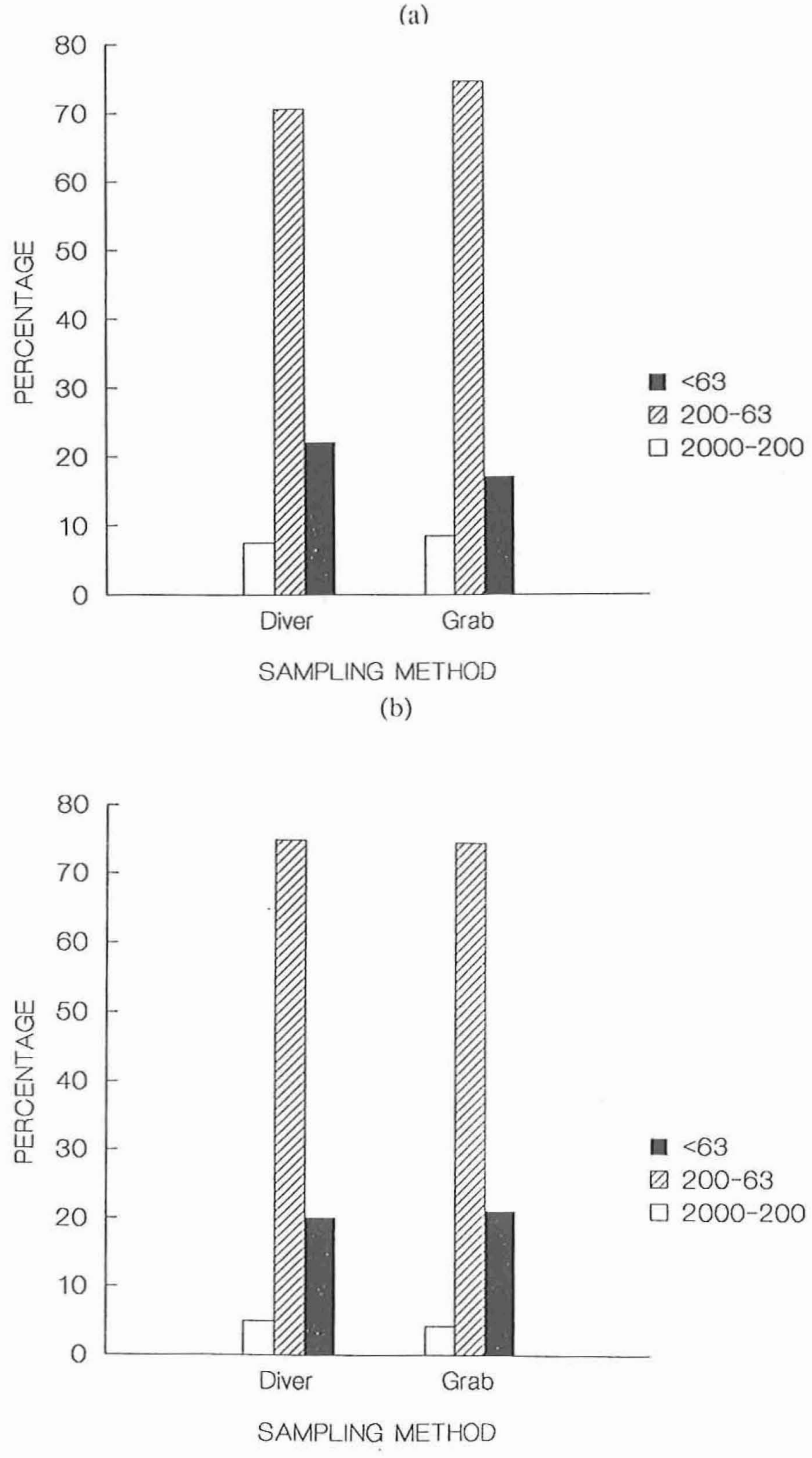


Figure 7. Particle size distribution as a percentage (by weight) of the <2 mm size fraction of sediment samples collected by diver (using hand cores) and a Smith-MacIntyre grab at station S10 during (a) the pre-monsoon season, and (b) the post-monsoon season. The size-class fractions are 2000-200 μm, 200-63 μm and <63 μm.

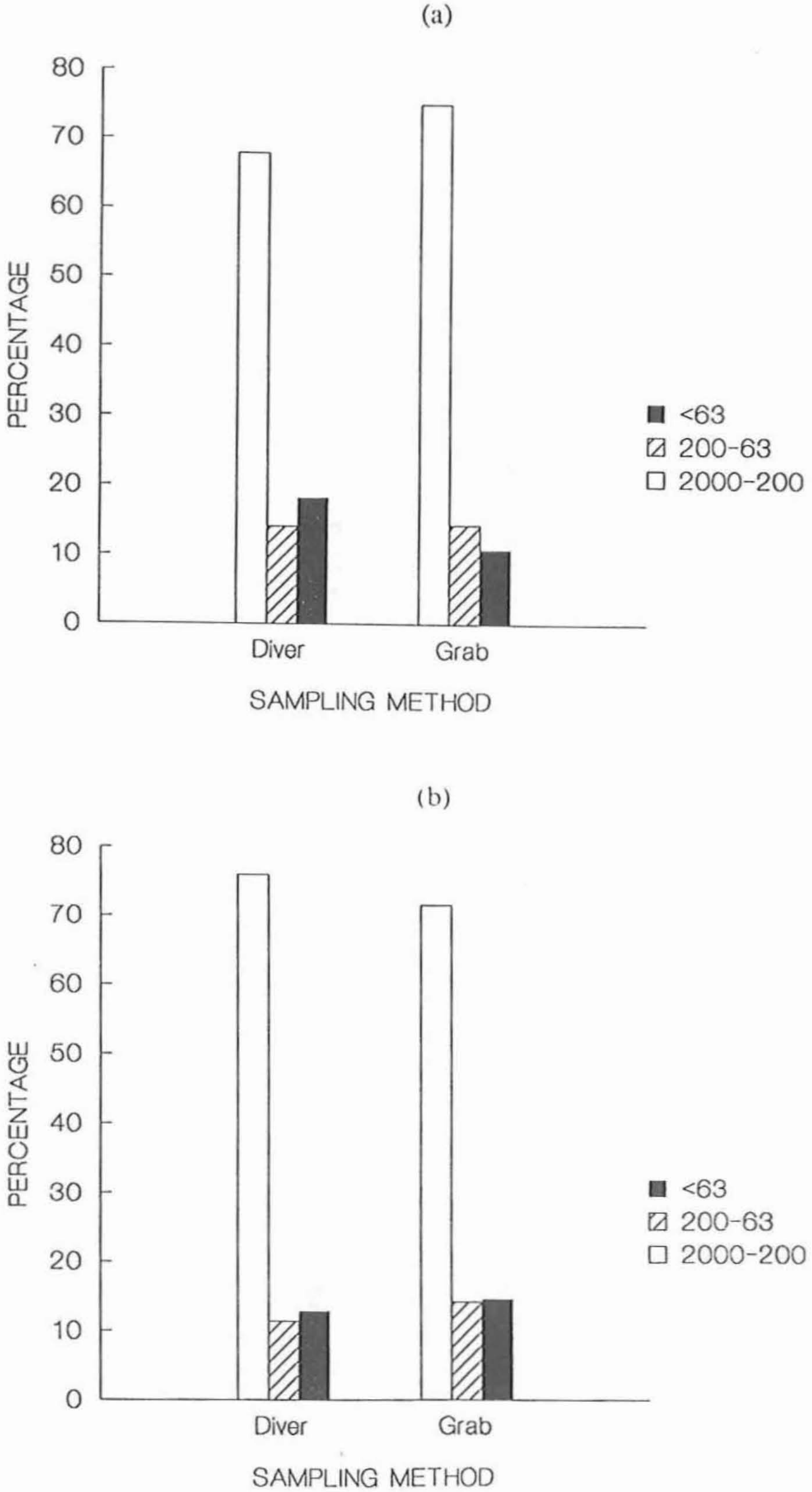


Figure 8. Particle size distribution as a percentage (by weight) of the <2 mm size fraction of sediment samples collected by diver (using hand cores) and a Smith-MacIntyre grab at station S2 during (a) the pre-monsoon season, and (b) the post-monsoon season. The size-class fractions are 2000-200 μm, 200-63 μm and <63 μm.

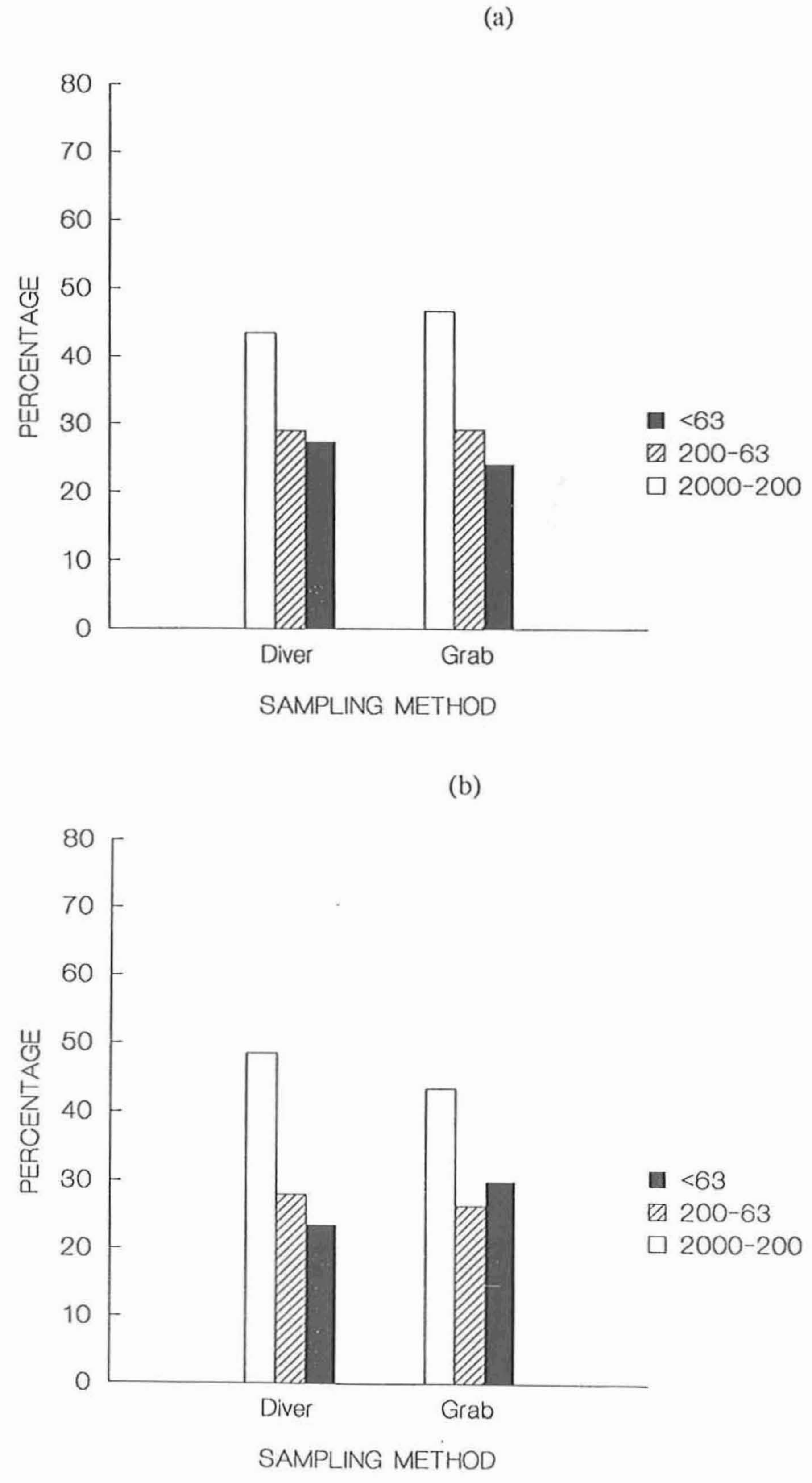


Figure 9. Particle size distribution as a percentage (by weight) of the <2 mm size fraction of sediment samples collected by diver (using hand cores) and a Smith-MacIntyre grab at station S5 during (a) the pre-monsoon season, and (b) the post-monsoon season. The size-class fractions are 2000-200 μm, 200-63 μm and <63 μm.

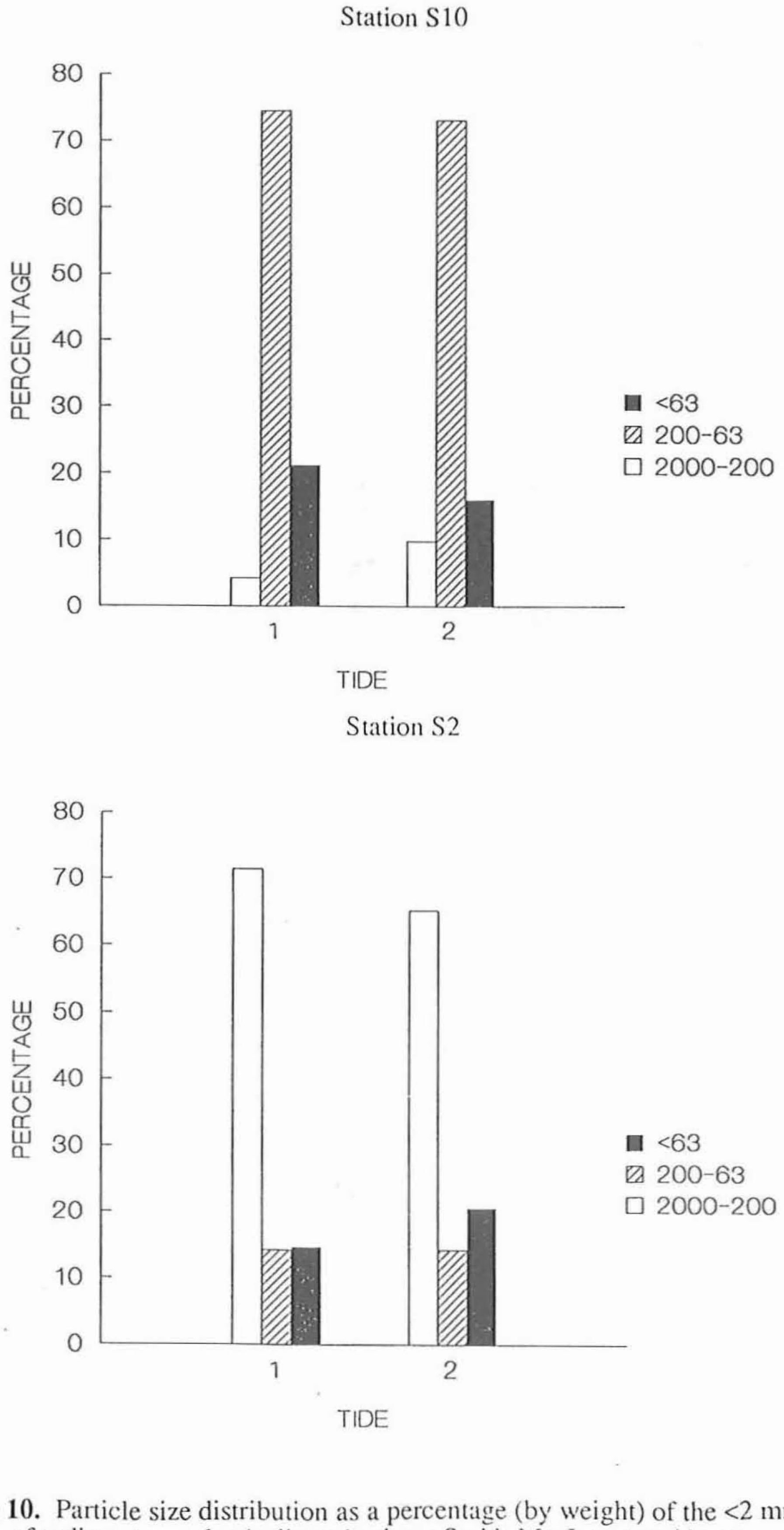


Figure 10. Particle size distribution as a percentage (by weight) of the <2 mm size fraction of sediment samples (collected using a Smith-MacIntyre grab) at two stages in the tidal cycle from station S10 and S2 during the post-monsoon season. The size-class fractions are 2000-200 μm, 200-63 μm and <63 μm.

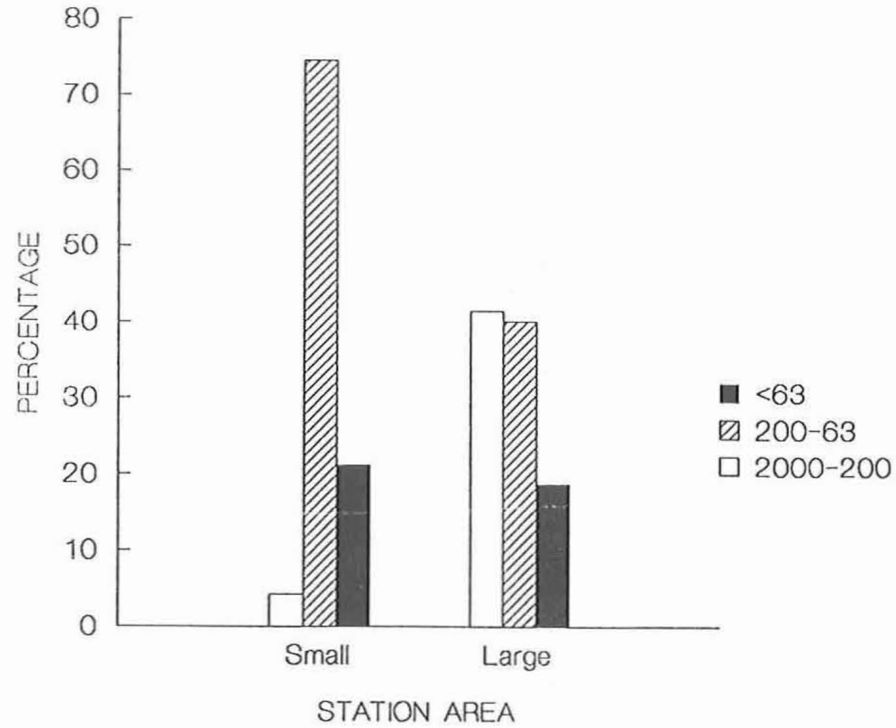


Figure 11. Particle size distribution as a percentage (by weight) of the <2 mm size fraction of sediment samples collected (using a Smith-MacIntyre grab) over two different areas (sizes) from station S10 during the post-monsoon season. The size-class fractions are 2000-200 µm, 200-63 µm and <63 µm.

Twelve metals or elements, aluminium (Al), arsenic (As), cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), mercury (Hg), manganese (Mn), nickel (Ni), lead (Pb), silica (Si) and zinc (Zn), are negatively correlated with the 2000-200 mm size fraction and postively correlated with the finer (200-63 and <63 µm) size fractions. These same twelve metals are also negatively correlated with sediment $CaCO_3$ content. In contrast, calcium (Ca), cadmium (Cd), manganese (Mg) and selenium (Se) are positively correlated with the 2000-200 µm size fraction, negatively correlated with the finer (200-63 and <63 µm) size fractions, and positively correlated with $CaCO_3$ content. Arsenic (As), mercury (Hg) and selenium (Se), in particular, are poorly correlated with any of the physico-chemical parameters. The poor correlations for selenium and, in particular, mercury may be in part a consequence of the high proportion of samples which had concentrations below the detections limit (0.05 and 0.10 mg kg^{-1} for mercury and selenium respectively). Copper (Cu) followed by aluminium (Al), nickel (Ni), silica (Si) and zinc (Zn) concentrations have the strongest positive correlation with the organic carbon content within sediments.

The relationship between the suite of trace metals and aluminium (Al) concentration (Table 3) mirrors the patterns displayed by the finer (200-63 and <63 µm) sediment size fractions with aluminium. The correlation coefficients for arsenic (As), calcium (Ca), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), magnesium

(Mg), manganese (Mn), nickel (Ni), lead (Pb), silica (Si) and zinc (Zn) are, in fact, substantially higher for aluminium than any single sediment size fraction or combination of size fractions.

Table 3. Pearson correlation matrix between grain size (2000-200 μm, 200-63 μm and <63 μm size fractions), calcium carbonate ($CaCO_3$) and organic carbon content, and trace metal concentrations within sediment from the Torres Strait.

	2000-200μm	200-63μm	<63μm	$CaCO_3$	Organic carbon	Trace metal conc. ($\log_e$metal)
2000-200μm	1.000					
200-63μm	-0.901	.1.000				
<63μm	-0.763	0.408	1.000			
$CaCO_3$	0.886	-0.765	-0.726	1.000		
Organic carbon	-0.683	0.478	0.726	-0.762	1.000	
Al	-0.851	0.707	0.741	-0.980	0.775	1.000
As	-0.431	0.434	0.261	-0.636	0.444	0.677
Ca	0.773	-0.536	-0.830	0.893	-0.774	-0.866
Cd	0.606	-0.550	-0.456	0.700	-0.536	-0.694
Co	-0.783	0.670	0.651	-0.920	0.706	0.940
Cr	-0.767	0.715	0.551	-0.877	0.615	0.890
Cu	-0.789	0.586	0.790	-0.936	0.809	0.954
Fe	-0.701	0.629	0.541	-0.831	0.624	0.870
Hg	-0.181	0.081	0.261	-0.242	0.309	0.239
Mg	0.764	-0.590	-0.731	0.888	-0.658	-0.840
Mn	-0.729	0.630	0.597	-0.853	0.641	0.878
Ni	-0.832	0.704	0.703	-0.968	0.766	0.984
Pb	-0.650	0.569	0.521	-0.786	0.602	0.803
Se	0.253	-0.193	-0.245	0.290	-0.160	-0.281
Si	-0.864	0.754	0.698	-0.983	0.758	0.990
Zn	-0.834	0.722	0.680	-0.958	0.748	0.977

Aluminium concentration is plotted against the full suite of trace metals (As,Ca,Cd,Co,Cr,Cu,Fe,Hg,Mg,Mn,Ni,Pb,Se,Si and Zn) for which concentrations were determined in Appendix Figures 1 to 15. Regression analysis identifies five metals (Co,Cu,Ni,Si and Zn) which covary strongly (r^2 => 0.883) with aluminium, a further six (Ca,Cr,Fe,Mg,Mn and Pb) which also covary with aluminium (r^2 ranging between 0.644 and 0.792), and four (As,Cd,Hg and Se (r^2 <= 0.481)) which do not covary with aluminium.

Summary

Sampling stations S1 and S10 are characterized by fine grained (<200 μm) sediments which are low in calcium carbonate and high in organic carbon content. These sediments are believed to be derived primarily from terrestrial sources via river discharge, particularly station S1 which is dominated by the <63 μm size fraction. In contrast, sampling stations S3,S4 and S7 are characterized by coarse grained (>200 μm) sediments which are high in calcium carbonate and low in organic carbon content. These sediments are believed to be derived primarily from marine sources. Sampling S2,S5 and S6 display intermediate characteristics with sediments that are derived from both marine (particularly S5) and terrestrial (particularly S6) sources. Sampling station S2, while relatively close to the coast, lies in shallow water (approximately 3-4 metres) where sediment deposition and resuspension is dominated by physical processes, particularly by wind-driven surface gravity waves. Station S2 has proportionally less $CaCO_3$ than stations which lie within the central Torres Strait (S3,S4,S5 and S7).

There is no systematic difference in partical size distribution apparent among the two methods (hand-cores and grab) that were investigated to sample sediments. In particular, there is no apparent loss of fines from the grab. Similarly, variation in particle size distribution among samples collected at different stages of the tidal cycle are small and negligible when compared to differences among sampling stations. In contrast, the particle size distribution can vary markedly as a result of increasing the sampling area of the station.

Aluminium, cobalt, chromium, copper, iron, manganese, nickel, lead, silica and zinc concentrations are strongly and postively correlated with the finer (200-63 μm and <63 μm) size fractions, negatively correlated with sediment $CaCO_3$ content and are, therefore, believed to be derived primarily from terrestrial sources via river discharge. Arsenic, cadmium, magnesium, mercury and selenium concentrations do not appear to be associated primarily with terrigenous sediments. Aluminium concentration is identified as a geochemical normalizer for the comparison of calcium, cobalt, chromium, copper, iron, magnesium, manganese, nickel, lead, silica and zinc concentrations from areas which have different sediment grain size characteristics.

Trace metal concentrations

Two-way Analysis of Variance based on transformed metal concentrations ($\log_e$(concentration +1)) in surficial sediments from grab samples at eight locations (stations S1,S10,S2,S3,S4,S5,S6 and S7) within two seasons (pre- and post-monsoon) are presented in Appendix Table 1. All metals except mercury (Hg) and selenium (Se) display significant ($p<0.05$) differences among locations. Only cobalt (Co), magnesium (Mg) and silica (Si) display significant ($p<0.05$) differences among seasons while magnesium also displays a significant ($p<0.05$) interaction between season and location.

Two-way Analysis of Variance based on transformed metal concentrations ($\log_e$(concentration +1)) in surficial sediments collected using two methods (diver/hand-core and grab) within two seasons (pre- and post-monsoon) during the post-monsoon period are presented for stations S10,S2 and S5 in Appendix Tables 2 to 4 respectively. Only cadmium (Cd) at station S10 (Appendix Table 2) displays a significant ($p<0.05$) difference among methods. Aluminium (Al) at stations S10 and S2, cadmium (Cd) at S2 and S5, cobalt (Co) at S10 and S2, lead (Pb) at S10, and mercury (Hg), magnesium (Mg) and manganese (Mn) at station S2 display significant ($p<=0.05$) differences among seasons. Arsenic (As) at station S2 (Table 6) and cadmium (Cd) at S5 (Appendix Table 4) display a significant ($P<0.05$) interaction between season and method.

One-way Analysis of Variance based on transformed metal concentrations ($\log_e$(concentration +1)) in surficial sediments from grab samples collected at two stages in the tidal cycle during the post-monsoon period are presented for stations S10 and S2 in Appendix Tables 5 and 6 respectively. Only aluminium (Al) and cadmium (Cd) at station S10 display significant ($p<0.05$) differences among stages of the tidal cycle.

One-way Analysis of Variance based on transformed metal concentrations ($\log_e$(concentration +1)) in surficial sediments from grab samples collected over two different station areas (sizes) from S10 during the post-monsoon period are presented in Appendix Table 7. Five metals, arsenic (As), cadmium (Cd), cobalt (Co), iron (Fe) and lead (Pb), display significant ($p<0.05$) differences as a consequence of increasing the sampling area of the station.

Concentrations (mg kg^{-1}) of the fifteen trace metals (Al,As,Cd,Co,Cr,Cu,Fe, Hg,Mg,Mn,Ni,Pb,Se,Si and Zn) from all eight sampling stations within the two seasons are presented in Appendix Tables 8 to 22.

Methodologies

Only cadmium concentration displayed a significant difference among collection methods (hand-cores and grab), at station S10 but not at S2 or S5. Cadmium concentration was higher in the grab samples (Appendix Table 10b). The significant interactions between method and season for arsenic at station S2 and cadmium at S5 arose as a consequence of concentrations being higher in samples collected using a particular method in one season but lower in samples using the same method during the other season. There are no other significant differences in metal concentrations or apparent patterns as a result of using one method or the other to collect sediment samples. Neither arsenic nor cadmium was strongly correlated with sediment grain size.

Only aluminium and cadmium concentrations at station S10, but not S2, displayed significant ($p<0.05$) differences among stages of the tidal cycle. Aluminium concentrations were highest during the second sampling while cadmium concentrations were highest during the first. Aluminium concentrations were also substantially higher at station S2 during the second sampling. The increase in aluminium concentration corresponded to a increase in the proportion of fines (<63 μm) in the sediment at station S2 but a decrease in the proportion of fines (<63 μm) at station S10 (Fig. 10).

Arsenic, cadmium, cobalt, iron and lead concentrations were significantly different in samples from station S10 as a consequence of increasing the sampling area of the station. While arsenic, cobalt, iron and lead concentrations were highest in samples from the large area, cadmium concentration was correspondingly lower. Chromium and manganese concentrations were also substantially higher in samples from the larger area, but this difference was not statistically significant ($p>0.05$). The larger sampling area was characterized by an increase in the coarse particle size fraction (2000-200 μm) at the expense of a decrease in the intermediate size fraction (200-63 μm) (see Fig. 11). Such differences in metal concentrations cannot, therefore, be attributed to differences in the sediment particle size distribution.

Seasonal patterns

Only cobalt, magnesium and silica concentrations displayed significant differences among seasons, while magnesium also displayed a significant interaction between season and location (Appendix Table 1). Magnesium concentrations were markedly higher at stations S1 and S10 during the post-monsoon sampling period while concentrations from stations S2,S3,S4 and S6 were markedly lower during the same period. Cobalt and silica concentrations were both significantly higher in samples collected during the post-monsoon period (see Appendix Tables 11b and 21b).

On the basis of both grab and hand-core samples from station S10, aluminium and lead concentrations were both significantly higher during the pre-monsoon period (Fig. 12;

Appendix Tables 2, 8b and 19b) while cobalt concentration was highest during the post-monsoon season (Fig. 12; Appendix Tables 2 and 11b). On the same basis at station S2, aluminium, cadmium and cobalt concentrations were significantly higher during the post-monsoon period (Fig. 13; Appendix Tables 3, 8b,10b and 11b) while mercury, magnesium and manganese were significantly higher during the pre-monsoon period (Fig. 14; Appendix Tables 3, 15b,16b and 17b). Nickel and silica concentrations were also markedly higher during the post-monsoon period (Appendix Tables 18b and 21b), but these differences were not statistically significant ($p>0.05$). At station S5, only cadmium concentrations from the grab samples were significantly higher during the pre-monsoon period (Appendix Tables 4 and 10b).

Increases in the concentration of cobalt, nickel and silica in samples collected during the post-monsoon period mirror a general increase in the fine grain sediment size fraction (<63 μm), with which they are positively correlated, at most sampling stations during the same period. However, the same is not true for aluminium at station S10 and manganese at S2.

Spatial patterns

Spatial variation in the concentration of aluminium, arsenic, calcium, cadmium, cobalt, chromium, copper, iron, magnesium, manganese, nickel, lead, silica and zinc, all of which displayed significant differences among locations (Appendix Table 1), is presented graphically in Appendix Figures 16 to 29 respectively. Aluminium, cobalt, chromium, copper, iron, manganese, nickel, lead, silica and zinc concentrations were all highest at station S1, followed by S10 and/or S6, and then station S2 (Appendix Figs. 16,20,21,22,23,25,26,27,28 and 29 respectively). Station S5 displayed the next highest concentrations, however, they were rarely significantly different from concentrations of the same metals at stations S3,S4 and S7. Arsenic, calcium, cadmium and magnesium concentrations were highest at stations S6,S7,S3 and S3 respectively, while calcium, cadmium and magnesium concentrations were lowest at station S1 (Appendix Figs. 17,18,19 and 24 respectively). Mercury and selenium concentrations did not differ significantly among all sampling locations. These three patterns are presented graphically for copper, cadmium and selenium in Figures 15 to 17.

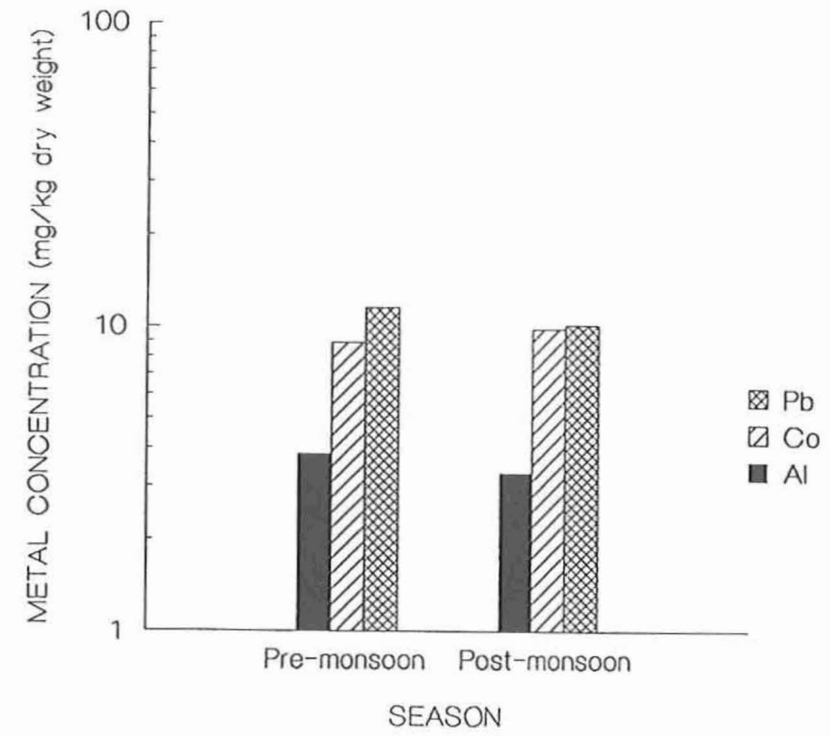


Figure 12. Aluminium (Al), cobalt (Co) and lead (Pb) concentrations in sediments (collected using both hand-corer and grab) from station S10 within two seasons. Aluminium and lead concentrations were both significantly higher during the pre-monsoon season while cobalt concentration was highest during the post-monsoon season.

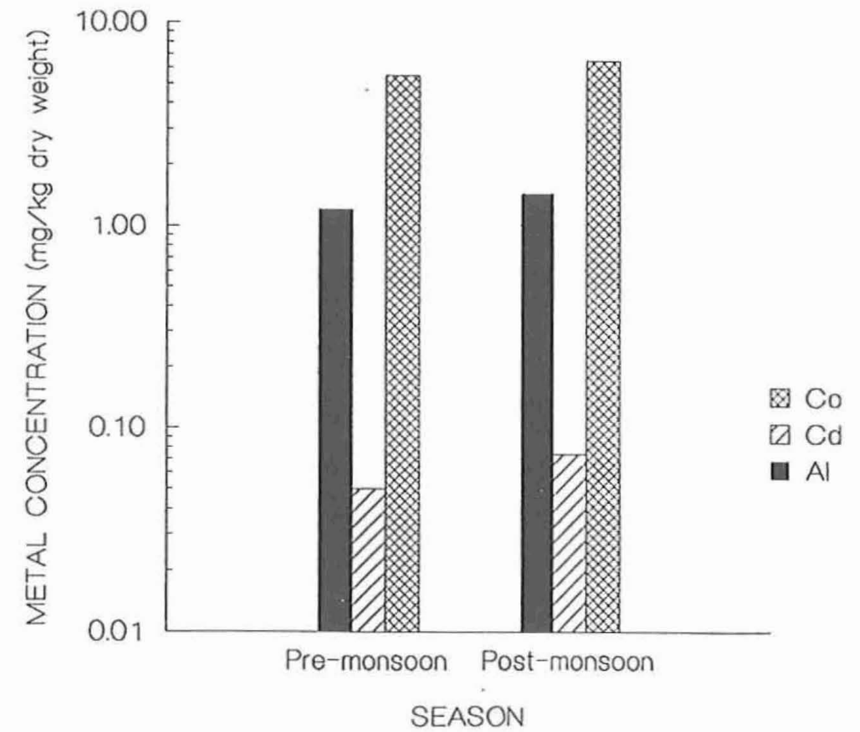


Figure 13. Aluminium (Al), cadmium (Cd) and cobalt (Co) concentrations in sediments (collected using both hand-corer and grab) from station S2 within two seasons. The concentrations of all three trace metals were significantly higher during the post-monsoon season

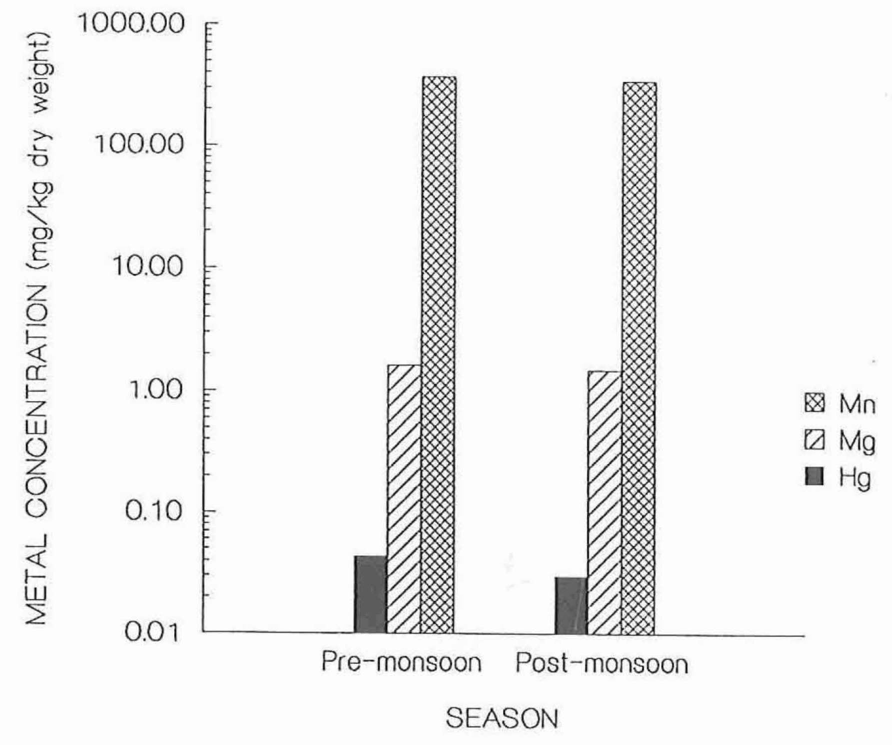


Figure 14. Mercury (Hg), magnesium (Mg) and manganese (Mn) concentrations in sediments (collected using both hand-corer and grab) from station S2 within two seasons. The concentrations of all three trace metals were significantly higher during the pre-monsoon season.

When normalized to aluminium concentration, station S2 had significantly ($P<0.05$) higher concentrations of cobalt, chromium, copper, iron, magnesium, manganese, nickel, lead and silica than station S1. Al-normalized zinc concentrations were not significantly different ($p>0.05$) between the two locations. Overall, the highest Al-normalized concentrations of cobalt, copper, nickel, lead and silica were at station S4, while the highest Al-normalized chromium and iron concentrations were found at station S2.

When normalized to the <200 μm sediment size fraction, station S2 has significantly ($P<0.05$) higher concentrations of chromium, iron, magnesium and manganese than S1. <200 μm-normalized cobalt, copper, nickel, lead, silica and zinc concentrations were not significantly different ($p>0.05$) between the two locations. The highest <200 μm-normalized concentrations of cobalt, copper, magnesium, nickel, lead and silica were at station S4, while the highest <200 μm-normalized chromium, iron and manganese concentrations were found at station S2.

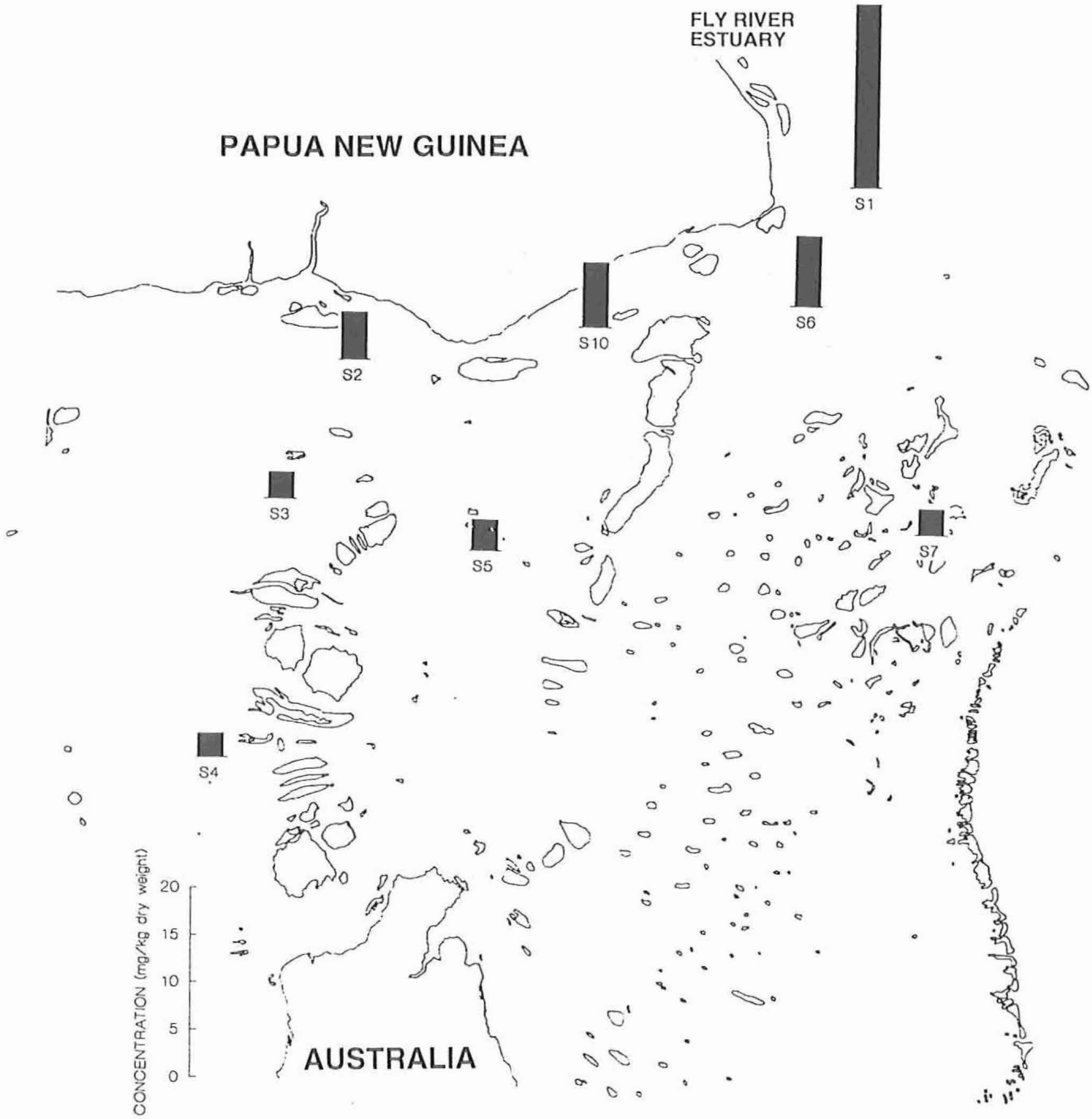


Figure 15. Spatial distribution of copper (Cu) concentration (averaged over two seasons) in sediments (collected using a Smith-McIntyre grab) from all sampling stations.

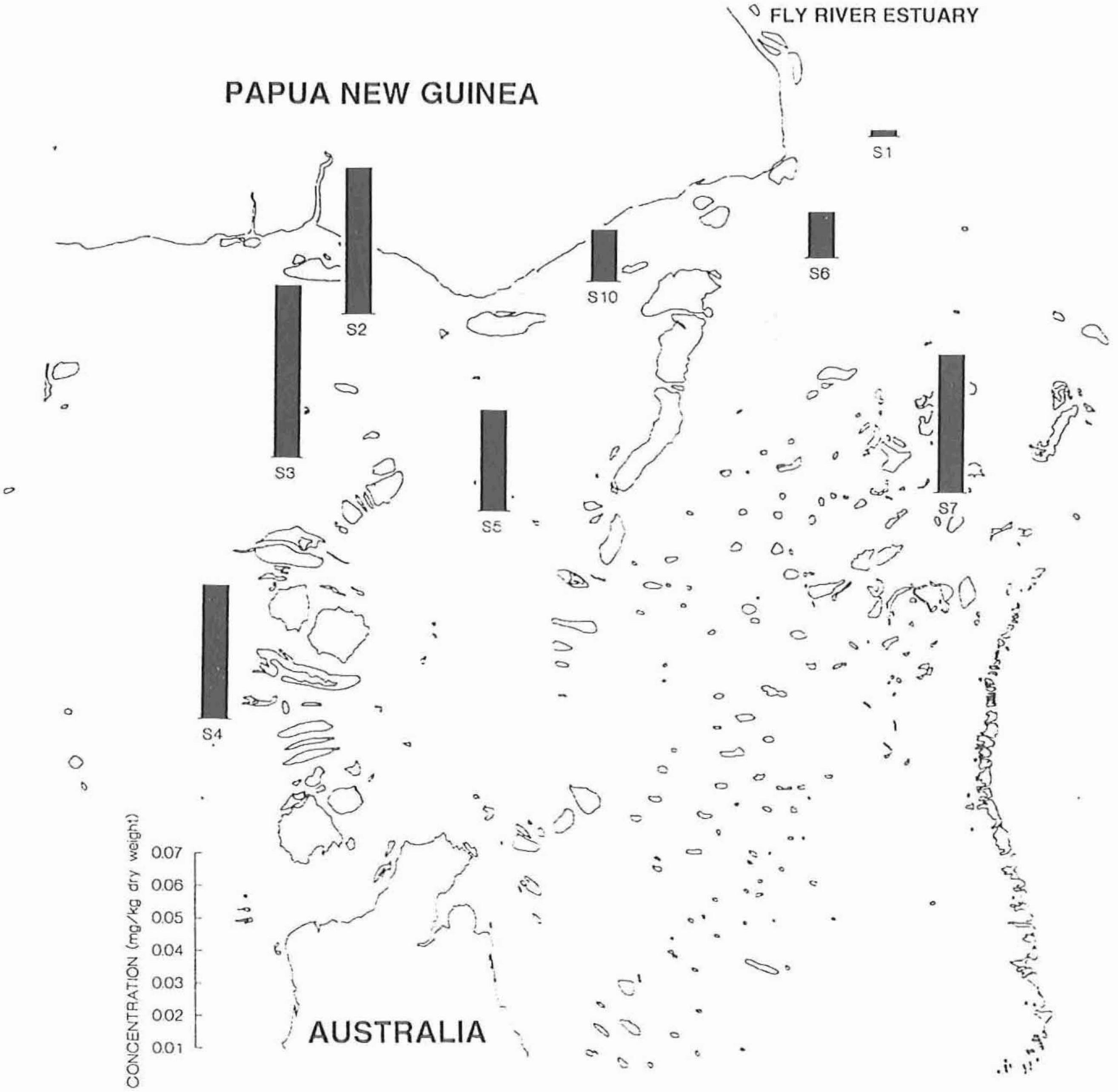


Figure 16. Spatial distribution of cadmium (Cd) concentration (averaged over two seasons) in sediments (collected using a Smith-McIntyre grab) from all sampling stations.

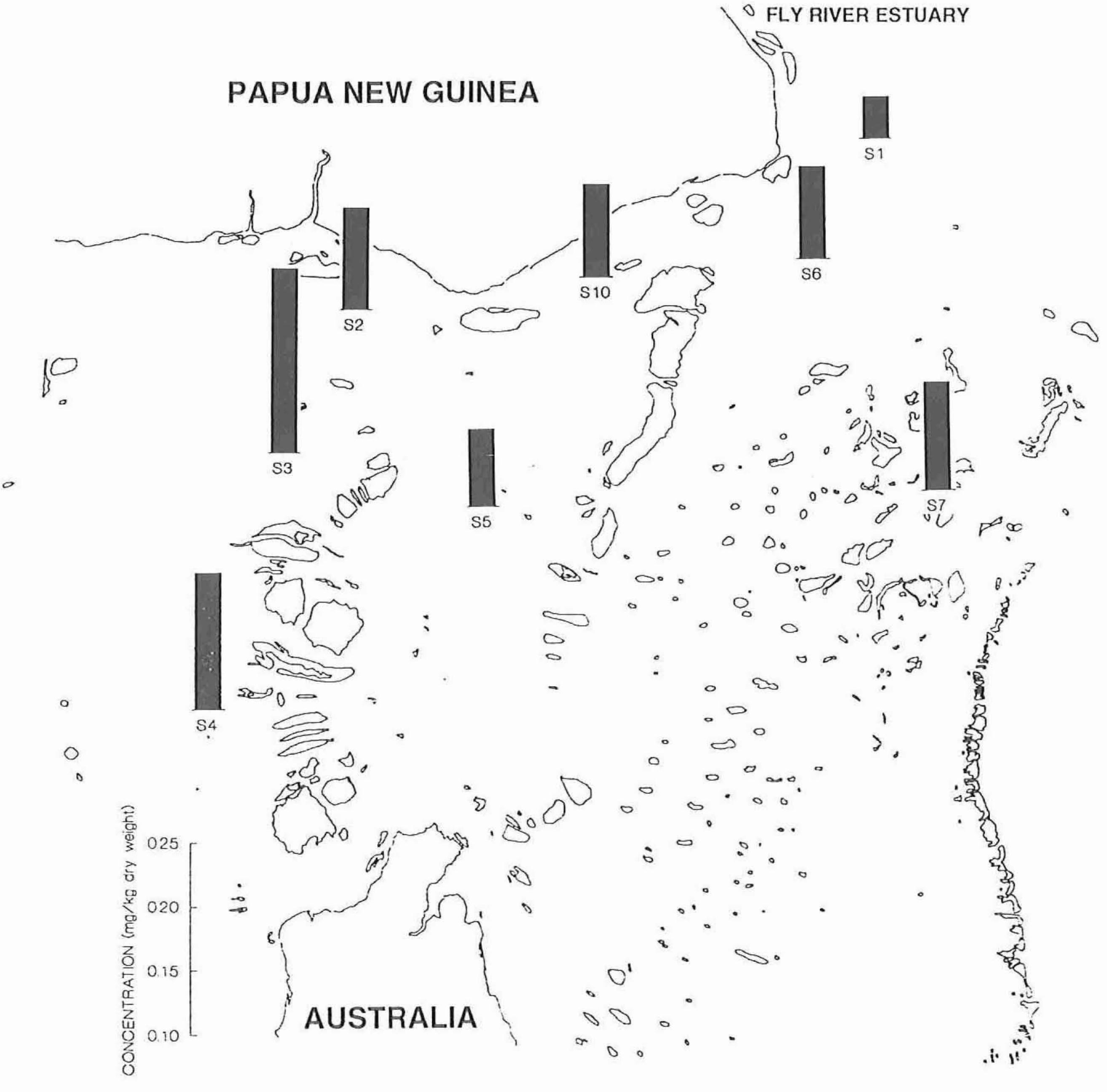


Figure 17. Spatial distribution of selenium (Se) concentration (averaged over two seasons) in sediments (collected using a Smith-McIntyre grab) from all sampling stations.

Summary

As only arsenic and cadmium concentrations varied significantly with sampling method, both of which are not strongly correlated with sediment grain size, the grab must be considered to function well and without appreciable loss of the fine (<63 mm) sediment size fraction with which most metal is associated. Similarly, it is apparent that metal concentration is largely unaffected by sampling at different phases of the tidal cycle. The observed differences in aluminium, arsenic and cadmium concentrations as a consequence of sampling method and tidal cycle are likely to have resulted from natural variability in the concentrations of these metals within the sediments. In contrast, metal concentrations are likely to vary significantly as a result of sampling from different station areas.

There is some evidence of an increase in the concentrations of cobalt, nickel and silica, particularly at stations closest to the PNG coast (S1,S10 and S2), which may be associated with a post-monsoon seasonal increase in the proportion of fine (<63 µm) sediment of terrigenous origin. However, this pattern is not evident for other metals which might also be expected to increase or decrease in concentration as the proportion of fine sediment varies.

The Fly River is evidently a major source of sediment to the northern Torres Strait as illustrated by the high concentrations of aluminium, cobalt, chromium, copper, iron, manganese, nickel, lead, silica and zinc at locations closest to the river mouth and PNG coast (S1,S10,S2 and S6). The concentrations of these metals become diluted by calcium carbonate sediments of marine origin farther from the river mouth and PNG coast. Both distance and water depth influence the degree of dilution. When metal concentrations are normalized in order to compensate for variation in the grain size characteristics of sediments from different locations, they appear to be higher at locations on the western side of the Torres Strait away from the Fly River. Caution should be exercised when comparing normalized concentrations where the normalizer (as the denominator) at one location is very small relative to another location. This is particularly the case when comparing coastal stations with those in the central Torres Strait.

Biota as Indicator Organisms

Thalassia hemprichii (seagrass)

Two-way Analysis of Variance based on transformed metal concentrations ($\log_e$(concentration+1)) in the leaf tissue of the seagrass *T. hemprichii* from Campbell Island and Dungeness Reef within two seasons (pre- and post-monsoon) is presented in Appendix Table 23. Only chromium (Cr) displayed a statistically significant ($p<=0.05$) difference among seasons while cobalt (Co) and nickel (Ni) displayed significant differences among locations. Both cobalt (Co) and zinc (Zn) displayed a statistically significant ($p<=0.05$) interaction between season and station. Mercury was not included in the analysis as all samples were below the detection limit (<0.05 mg kg^{-1} dry weight), while iron and manganese concentrations were not determined in samples collected during the pre-monsoon period as there was insufficient material available.

One-way Analysis of Variance based on metal concentrations from three locations, Campbell Island, Dungeness Reef and Kokope Reef, during the post-monsoon season is presented in Appendix Table 24. During the post-monsoon season four metals, cobalt (Co), manganese (Mn), lead (Pb) and zinc (Zn), displayed significant differences among the three locations.

The concentrations (mg kg^{-1} dry weight) of 11 metals from three sampling stations (Campbell Island, Dungeness Reef and Kokope Reef) within two seasons (pre- and post-monsoon) are presented in Appendix Tables 25 to 35.

Seasonal patterns

Chromium (Cr) displayed significantly higher concentrations at both Campbell Island and Dungeness Reef during the pre-monsoon period (Table 28). Three other metals, cadmium (Cd), copper (Cu) and zinc (Zn), also displayed a marked seasonal elevation in concentrations during the pre-monsoon period (Appendix Tables 26,29 and 35 respectively) but only at Campbell Island. However, these differences were not statistically significant.

Spatial patterns

Cobalt (Co), manganese (Mn), lead (Pb) and zinc (Zn) concentrations were all significantly higher at Kokope Reef than Campbell Island and/or Dungeness Reef during the post-monsoon period (Fig. 18; Appendix Tables 27, 31, 33 and 35 respectively). Cobalt, manganese and zinc concentrations were all higher at Dungeness Reef than Campbell Island. During the pre-monsoon period, the same pattern between Dungeness Reef (higher) and Campbell Island (lower) is evident for cobalt and nickel (Fig. 19) but not for zinc or copper which are markedly higher at Campbell Island.

Regional variation

There are no other known studies that have measured trace metal concentrations in *T. hemprichii.*

Thalassodendron ciliatum (seagrass)

One-way Analysis of Variance based on transformed metal concentrations ($\log_e$(concentration+1)) in the leaf tissue of the seagrass *T. ciliatum* from Dungeness and Kokope Reefs during the pre-monsoon season is presented in Appendix Table 36. Four metals, arsenic (As), cadmium (Cd), lead (Pb) and zinc (Zn), displayed statistically significant ($p<=0.05$) differences among the stations.

The concentrations (mg kg^{-1} dry weight) of 12 metals from two sampling stations (Dungeness and Kokope Reefs) during the pre-monsoon season are presented in Appendix Table 37.

Seasonal patterns

No samples were collected during the post-monsoon season.

Spatial patterns

The concentrations of lead and zinc were both significantly higher at Kokope Reef than Dungeness Reef while concentrations of arsenic and cadmium were higher at Dungeness Reef during the pre-monsoon period (Fig. 20). Chromium concentrations were also markedly higher at Dungeness Reef. While not strictly comparable because

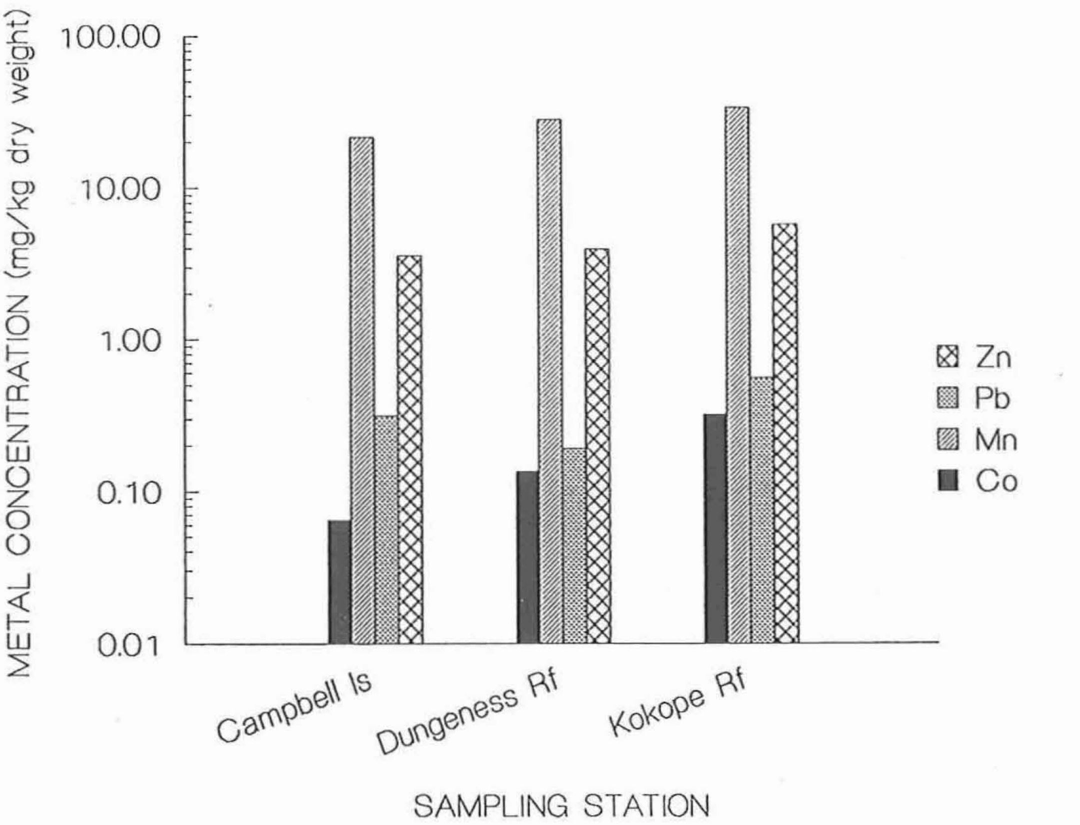


Figure 18. Cobalt (Co), manganese (Mn), lead (Pb) and zinc (Zn) concentrations in the leaf tissue of the seagrass *T. hemprichii* from three locations during the post-monsoon season. The concentrations of all four metals are significantly higher at Kokope Reef than Campbell Island and/or Dungeness Reef

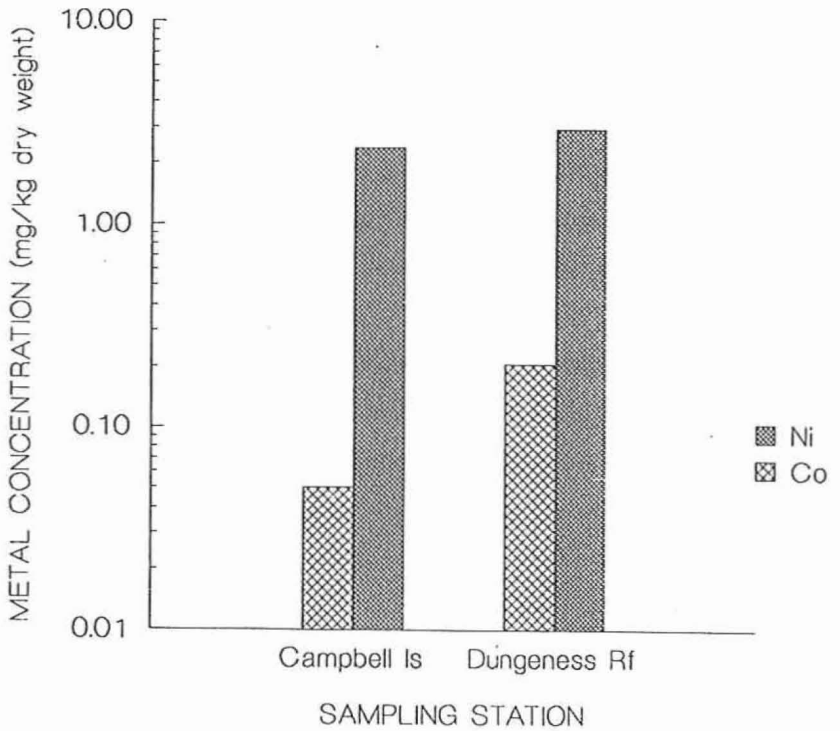


Figure 19. Cobalt (Co) and Nickel (Ni) concentrations in the leaf tissue of the seagrass *T. hemprichii* from two locations during the pre-monsoon season. The concentrations of both metals are significantly higher at Dungeness Reef.

sampling was conducted in different seasons, there is general agreement with the spatial patterns displayed by *T. hemprichii* except for arsenic and chromium.

Regional variation

There are no other known studies that have measured trace metal concentrations in *T. ciliatum.*

***Tridacna crocea* (boring clam)**

Initial evaluation of the data showed that the clams collected during the pre-monsoon period from all four stations that were sampled had a wider range of shell lengths than those collected during the post-monsoon period. Shell length and tissue weight were positively correlated and significantly different from zero ($P<=0.05$) at all four stations during the pre-monsoon period, but not during the post-monsoon season. Five of the sixteen metals analysed (arsenic, cobalt, manganese, nickel and lead) in pre-monsoon samples showed a positive correlation with shell length and tissue weight which was significantly different from zero ($p<=0.05$) at all four stations. The $\log_e$ of dry tissue weight consistently provided the strongest and most significant correlations. With the exception of arsenic, the slopes were also significantly different ($p<=0.05$) among locations. It was therefore evident that differences in the concentrations of these five metals between stations could result from variation in the size of individuals that were collected. Also, the wide size range of individuals would increase the sample variance making it more difficult to detect significant differences. Subsequent statistical analyses for these five metals were therefore performed on individuals with a shell length <= 82 mm. Selection of this smaller range of shell lengths resulted in reduced variances for these five metals with minimal reduction in sample size. Subsequently, there were no consistent, statistically significant correlations between shell length or tissue dry weight and concentration for any trace metals. All samples were included in the analyses for silver, aluminium, cadmium, chromium, copper, iron, mercury, selenium, strontium, uranium and zinc.

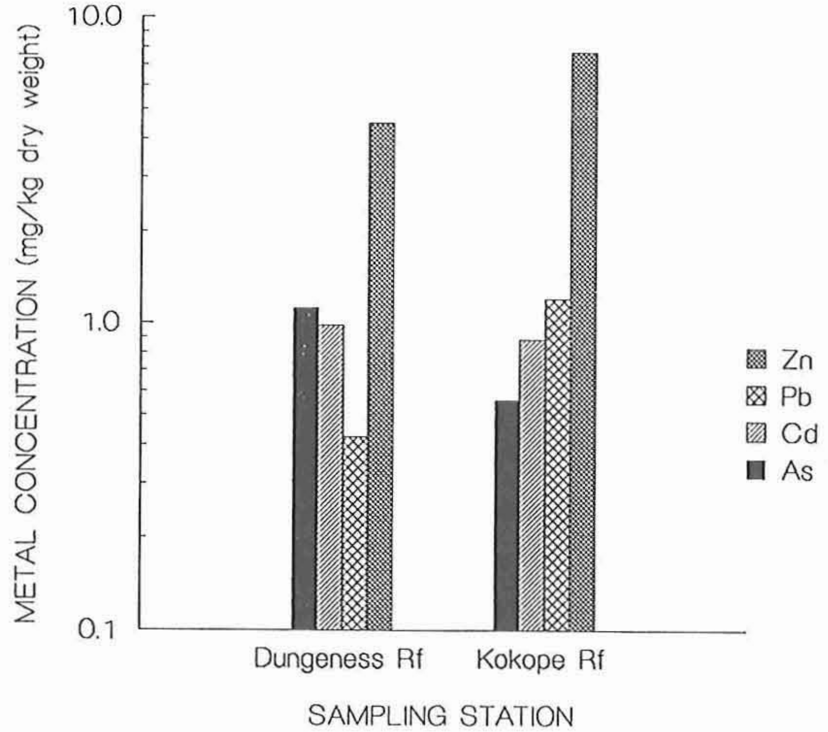


Figure 20. Arsenic (As), cadmium (Cd), lead (Pb) and zinc (Zn) concentrations in the leaf tissue of the seagrass *T. ciliatum* from two locations during the pre-monsoon season. Arsenic (As) and cadmium (Cd) concentrations are significantly higher at Dungeness Reef while lead and zinc concentrations are highest at Kokope Reef.

Many combinations of metals displayed correlations which were significantly different from zero ($p<=0.05$) at individual locations within a season. However, these correlations were rarely consistently significant across all locations and seasons. The following relationships between logarithmically transformed metal concentrations were all positive and significantly different from zero across all locations and seasons: cadmium & zinc; cobalt & manganese; and cobalt & nickel.

Two-way Analysis of Variance based on transformed metal concentrations ($\log_e$(concentration+1)) in the kidney tissue of *T. crocea* are presented in Appendix Table 38. Four metals, aluminium (Al), chromium (Cr), manganese (Mn) and strontium (Sr), showed no statistically significant differences ($p>0.05$) among seasons or sampling stations. Eight metals, arsenic (As), cadmium (Cd), cobalt (Co), mercury (Hg), nickel (Ni), lead (Pb), selenium (Se) and uranium (U), displayed statistically significant differences ($p<=0.05$) among seasons while six, silver (Ag), cadmium (Cd), copper (Cu), iron (Fe), nickel (Ni) and zinc (Zn), showed significant differences ($p<=0.05$) among sampling stations. Only zinc (Zn) displayed a statistically significant interaction ($p=0.05$) between season and station.

The concentrations (mg kg^{-1} dry weight) of all 16 metals from the four sampling stations (Aureed Island, Campbell Island, Dungeness Reef and Kokope Reef) within two seasons (pre- and post-monsoon) are presented in Appendix Tables 39 to 54.

Seasonal patterns

Six metals (As,Cd,Co,Ni,Pb and U) showed significantly higher concentrations among locations during the post-monsoon sampling period (Appendix Table 38). These results are presented graphically for Kokope Reef in Figure 21. However, the concentration of cadmium was elevated only in samples from Kokope Reef, Campbell Island and Dungeness Reef during the post-monsoon period, while actually lower at Aureed Island during the same period (Appendix Table 42b). The significant interaction identified above for zinc resulted from elevated concentrations during the post-monsoon sampling period at Kokope Reef, Campbell Island and Dungeness Reef while concentrations were lower during the same period at Aureed Island. This general pattern is also evident in the concentrations of copper and strontium, both of which displayed elevated concentrations in samples from Campbell Island and Kokope Reef during the post-monsoon period, while concentrations of the same metals at Aureed Island during the post-monsoon period were reduced (Appendix Tables 45b and 52).

Only two metals (Hg and Se) showed significantly higher concentrations across all four locations during the pre-monsoon sampling period (e.g. see Figure 22 for Kokope Reef), although aluminium concentrations were also markedly higher during the pre-monsoon sampling period. Seasonal differences in metal concentrations cannot be attributed to changes in tissue weight as no difference in the relationship between shell length and kidney tissue weight is evident among seasons for any of the locations (see Figs. 23 and 24 for Campbell Island and Kokope Reef respectively).

Spatial patterns

Mean concentrations (mg kg^{-1} dry weight) over two seasons of the six metals (Ag,Cd,Cu,Fe,Ni and Zn) which showed significant differences among locations are presented graphically in Figure 25 (see also Appendix Tables 39a,42a,45a,46a,49a and 54a).

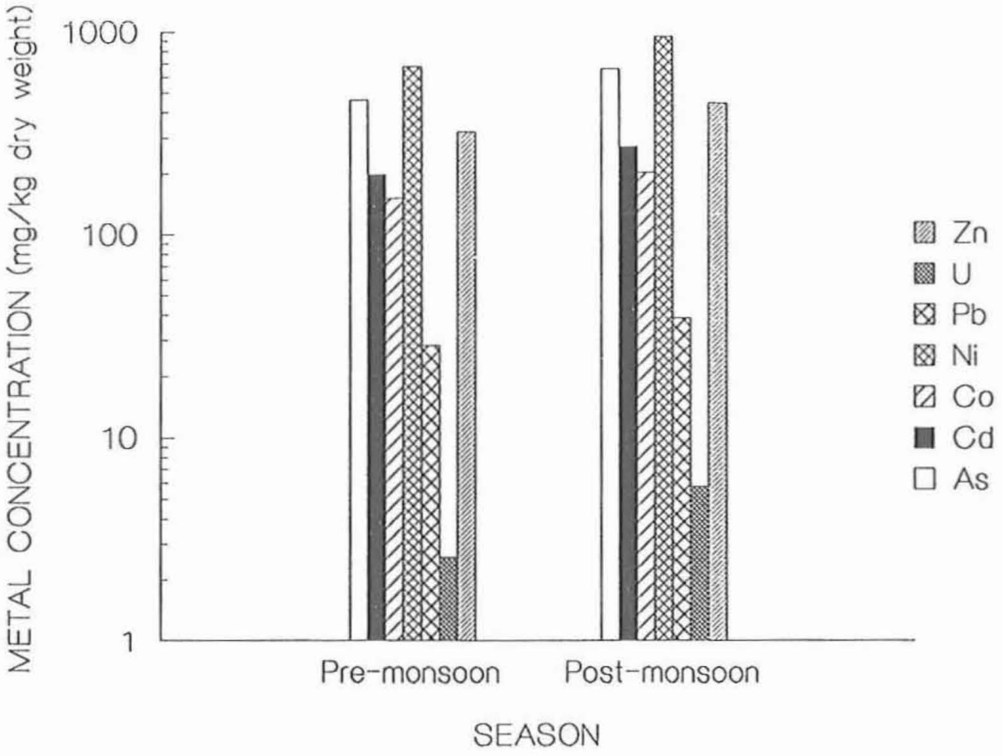


Figure 21. Arsenic (As), cadmium (Cd), cobalt (Co), nickel (Ni), lead (Pb), uranium (U) and zinc (Zn) concentrations in the kidney of the clam *T. crocea* from Kokope Reef during two seasons. The concentrations of all metals illustrated were significantly higher during the post-monsoon season.

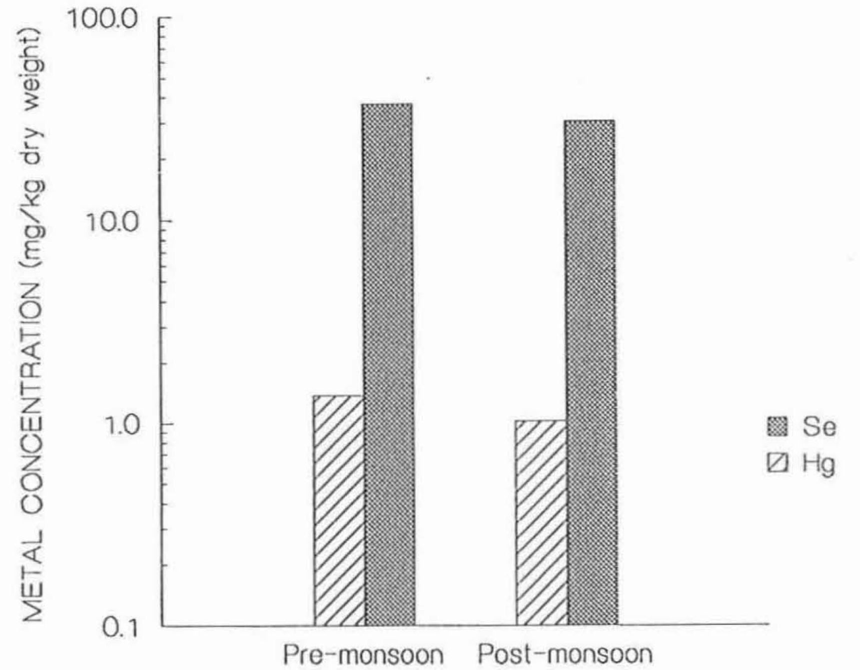


Figure 22. Mercury (Hg) and selenium (Se) concentrations in the kidney of the clam *T. crocea* from Kokope Reef during two seasons. The concentrations of both metals were significantly lower during the post-monsoon season.

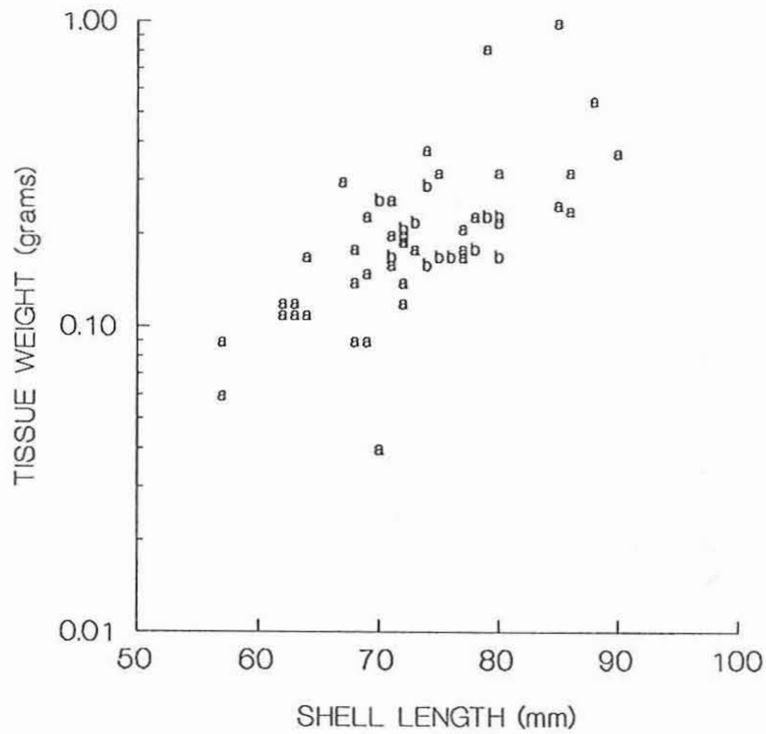


Figure 23. Relationship between shell length and kidney tissue dry weight in the clam *T. crocea* from Campbell Island. Samples are from the pre-monsoon (a) and post-monsoon (b) periods.

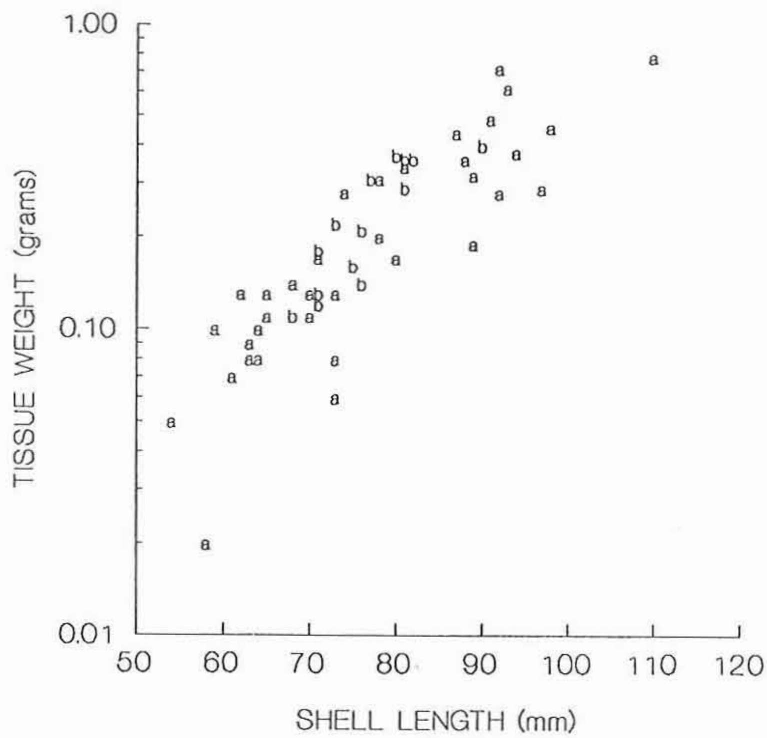


Figure 24. Relationship between shell length and kidney tissue dry weight in the clam *T. crocea* from Kokope Reef. Samples are from the pre-monsoon (a) and post-monsoon (b) periods.

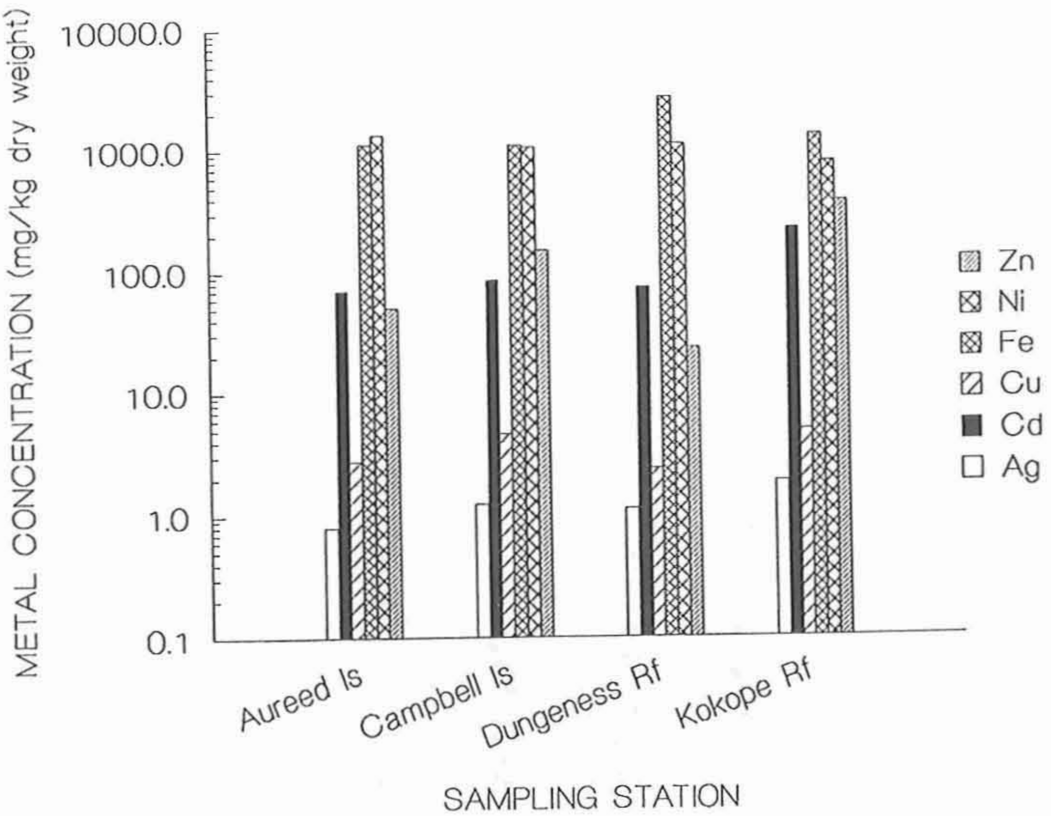


Figure 25. Silver (Ag), cadmium (Cd), copper (Cu), iron (Fe), nickel (Ni) and zinc (Zn) concentrations (mean of two seasons) in the kidney of the clam *T. crocea* from four locations. The concentrations of all metals illustrated were significantly different among locations.

Kokope Reef followed by Campbell Island displayed the highest concentrations of silver, cadmium, copper and zinc, while iron was highest at Dungeness Reef and nickel at Aureed Island. The data show that the concentrations of silver, cadmium, copper and zinc at Kokope Reef and Campbell Island were higher during the post-monsoon sampling period (Appendix Tables 39b,42b,45b and 49b respectively). Copper concentration at Kokope Reef is characterized by particularly high variance during the post-monsoon sampling period. While not statistically significant, the concentrations of aluminium, lead and strontium were also substantially higher at Kokope Reef, but not necessarily during the post-monsoon period. Iron concentrations were highest at Dungeness Reef during the pre-monsoon period while nickel concentrations were highest at Aureed Island during the post-monsoon period.

Only cadmium and zinc displayed statistically significant differences in concentrations among locations during both sampling periods (Appendix Tables 42b and 54b). Concentrations of these two metals at the four locations during each sampling period are presented graphically in Figures 26. From these figures it is evident that while the concentrations of both metals in samples from Kokope Reef, Campbell Island and Dungeness Reef increase over the monsoon period, concentrations decrease during the same period at Aureed Island.

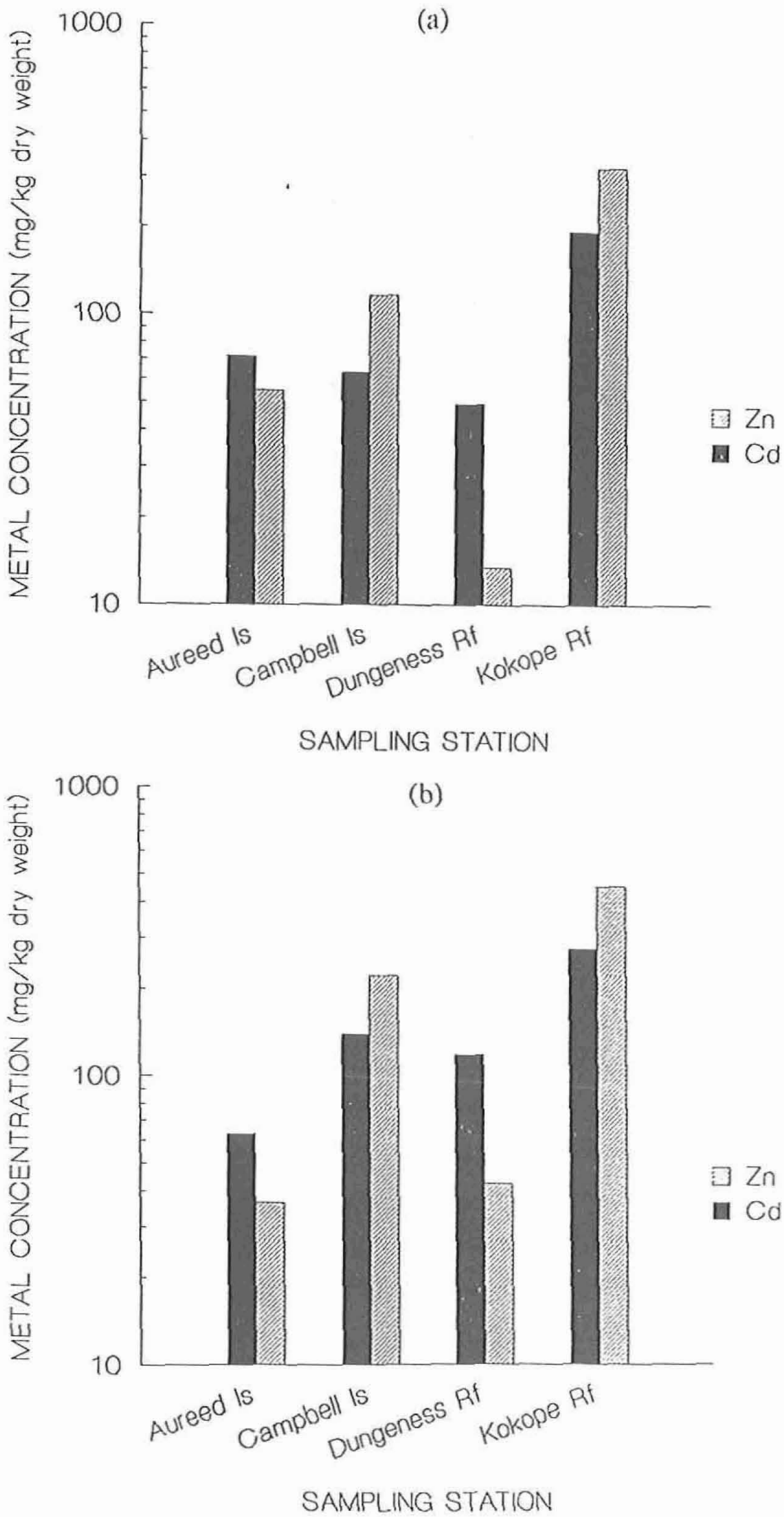


Figure 26. Cadmium (Cd) and zinc (Zn) concentrations in the kidney of the clam *T. crocea* from four locations during (a) the pre-monsoon season and (b) the post-monsoon season. The concentrations of both metals were significantly different among locations.

Regional variation

The concentrations of six metals (Cd,Cu,Hg,Ni,Pb and Zn) within the kidney of *T. crocea* from the present study are contrasted with results of other published studies from the Torres Strait and Great Barrier Reef (GBR) in Table 4. Only metals for which published data were available are listed. Note that there are three additional locations from the Torres Strait within the previously published studies: Yorke, Marakai and Zaigai Islands. One set of samples from Yorke Island was collected prior to the commencement of mining operations within the Fly River catchment while the other set is considered to be influenced by anthropogenic sources of metals.

The concentrations of mercury, nickel and lead in samples from all locations within the present study generally fall within the range of values that has been reported for similarly located (distance from the coast as nearshore, mid-shelf and off-shore) reefs within the GBR and Torres Strait. Only at Orpheus Island are concentrations of lead substantially higher than those found elsewhere in the GBR and Torres Strait. Orpheus Island, while situated in a relatively unpolluted environment, is located nearshore and influenced by both natural and anthropogenic sources of trace metals.

The mean and range of cadmium concentrations in samples from locations in the Torres Strait (this and previous studies) are generally higher that those found in the GBR. The only exception is the 1978 samples from Yorke Island. This may, however, be largely an artifact of the small sample size. The concentrations of cadmium from Kokope Reef are substantially higher than elsewhere in the Torres Strait and GBR. Similarly, the concentrations of copper in samples from Kokope Reef during the post-monsoon period are substantially higher than elsewhere. Otherwise, copper concentrations from locations in the Torres Strait are comparable with those found in the GBR. Zinc concentrations in samples from Campbell Island and, in particular, Kokope Reef during both sampling periods are substantially higher than elsewhere except for the 1985 samples from Yorke Island and Orpheus Island in the GBR. Both these latter locations are believed to be subjected to relatively minor inputs of trace metals from anthropogenic sources, including fishing and other vessels.

Table 4. Regional and seasonal variation in selected trace metal concentrations (mg kg^{-1} dry weight) within the kidney tissue of *T. crocea*. Data are mean and range (in parentheses). * Mercury concentrations in mg kg^{-1} wet weight. Sources = [1] This study; [2] Denton & Heitz, 1991; [3] Burdon-Jones & Denton, 1984a; [4] Burdon-Jones & Denton, 1984b. TS = Torres Strait. GBR = Great Barrier Reef. ndp = no data presented. n = number of samples. [a] Collected close to a popular mooring site for large fishing and other vessels.

Location	Collection Date	n	Cadmium	Copper	Mercury*	Nickel	Lead	Zinc
Aureed Island [1] (TS, mid-shelf)	October,1991	44	71.9 (1.3-172.0)	2.98 (1.9-4.4)	0.462 (0.249-0.732)	1164 (703-1690)	22.4 (12.1-47.0)	54.7 (2.2-154.0)
	April,1992	15	62.9 (10.0-160.0)	2.21 (1.2-3.7)	0.279 (0.126-0.450)	1427 (1000-2400)	24.5 (9.9-34.0)	36.4 (3.2-170.0)
Campbell Island [1] (TS, mid-shelf)	October,1991	37	63.6 (1.6-137.0)	4.4 (2.2-23.2)	0.498 (0.189-0.960)	844 (457-1590)	18.5 (8.7-33.1)	116.5 (5.1-274.0)
	April,1992	15	138.4 (77.0-200.0)	5.1 (2.5-8.9)	0.297 (0.198-0.450)	1305 (690-2300)	29.5 (17.0-47.0)	220.8 (22.0-430.0)
Dungeness Reef [1] (TS, mid-shelf)	October,1991	31	49.9 (5.6-104.0)	2.5 (1.3-3.9)	0.258 (0.081-0.426)	629 (227-1640)	11.8 (3.3-29.0)	13.3 (3.1-50.0)
	April,1992	15	118.4 (15.0-180.0)	2.1 (1.3-3.3)	0.216 (0.111-0.285)	1090 (650-2100)	18.5 (13.0-25.0)	42.4 (4.9-150.0)
Kokope Reef [1] (TS, nearshore)	October,1991	35	199.8 (63.6-593.0)	3.9 (2.1-9.2)	0.411 (0.213-0.822)	467 (156-930)	21.4 (6.4-56.3)	325.0 (87.0-628.0)
	April,1992	15	272.0 (110.0-420.0)	7.4 (1.6-62.0)	0.306 (0.093-0.480)	884 (270-1200)	37.4 (17.0-52.0)	448.1 (72.0-760.0)
Yorke Island [2] (TS, mid-shelf)	November, 1978	4	12.6 (2.9-27.5)	4.5 (3.8-4.9)	ndp	3018 (1762-4284)	31.1 (27.8-34.6)	7.7 (6.2-8.8)
	August,1985[a]	7	111 (44.5-243)	3.0 (1.7-4.6)	ndp	1023 (547-1566)	29.9 (28.2-37.3)	727 (242-1389)
Marakai Island [2] (TS, mid-shelf)	August,1985	8	140 (70.3-252)	4.6 (2.7-19.0)	ndp	1414 (911-2922)	47.7 (22.2-60.3)	5.9 (1.8-98.1)

(Table 4 continued over)

Location	Collection Date	n	Cadmium	Copper	Mercury*	Nickel	Lead	Zinc
Zaigai Island [2] (TS, mid-shelf)	June,1985	4	119 (75.7-173)	4.3 (4.1-6.0)	ndp	801 (256-1324)	28.4 (21.5-35.2)	14.3 (4.3-114)
(Lizard Island [3,4] (GBR, mid-shelf)	February, 1981	10	13.41 (1.80-60.59)	3.54 (2.51-5.02)	0.524 (0.297-0.745)	2352 (1176-3089)	35.77 (20.30-59.41)	43.76 (4.89-218)
	April,1982	10	6.51 (2.18-30.85)	2.77 (2.22-4.30)	0.476 (0.330-0.758)	2430 (1482-3988)	48.05 (38.93-61.16)	67.31 (12.69-313)
	July,1982	10	7.23 (1.61-34.85)	3.11 (2.38-4.30)	0.469 (0.286-0.750)	2113 (948-4624)	43.84 (34.60-74.89)	84.84 (10.13-397)
	October,1982	10	5.72 (1.97-30.34)	2.92 (2.09-4.02)	0.580 (0.260-0.953)	2214 (1205-4721)	50.80 (31.73-79.45)	103.0 (9.29-292)
	January,1983	10	5.09 (1.05-59.26)	3.93 (1.98-5.54)	0.429 (0.301-0.676)	2109 (889-3854)	42.87 (29.18-52.31)	70.92 (12.18-296)
Orpheus Island [3,4] (GBR, nearshore)	December,1980	14	40.60 (9.34-100)	4.52 (3.10-6.08)	0.864 (0.485-1.433)	1300 (799-2465)	117 (75.80-143)	485 (37.0-1287)
	April,1982	10	30.50 (8.26-135)	5.84 (3.54-15.18)	1.130 (0.805-1.670)	1860 (1571-2392)	82.12 (48.09-138)	405 (99.46-880)
	July,1982	10	20.66 (8.06-35.89)	4.73 (3.34-7.18)	0.973 (0.558-1.603)	1667 (1083-3067)	89.09 (69.53-121)	222 (46.5-634)
	October,1982	10	43.63 (12.42-106)	5.40 (3.28-20.19)	1.249 (0.600-1.731)	1845 (1179-2526)	89.20 (61.60-132)	385 (140-694)
	January,1983	10	24.65 (6.02-54.06)	3.86 (2.58-5.97)	0.999 (0.753-1.667)	1860 (1176-2733)	78.83 (39.23-136)	276 (78.09-708)
Carter Reef [3] (GBR, offshore)	February, 1981	4	16.53 (3.37-26.03)	3.83 (3.48-4.07)	0.446 (0.288-0.597)	2389 (1571-4192)	17.51 (10.05-23.75)	9.99 (4.38-14.18)
Linnet Reef [3] (GBR, nearshore)	February, 1981	10	14.11 (2.64-32.31)	3.55 (2.52-4.79)	0.504 (0.339-0.711)	1436 (831-3224)	56.07 (20.80-121)	61.44 (9.56-196)

Tridacna maxima (rugose giant clam)*

Shell length and tissue weight were positively correlated at all locations within both seasons, but not significantly different from zero (P>0.05) except for Raine Island. There were no consistent correlations between shell length or tissue weight and metal concentrations.

Many combinations of metals displayed correlations which were significantly different from zero (p<=0.05) at individual locations within a season. Once again these correlations were rarely consistently significant across all locations and seasons. The following relationships between logarithmically transformed metal concentrations were significantly different from zero across all locations and seasons: cadmium & zinc; cobalt & manganese; and cobalt & nickel. These were the same three combinations of metals that displayed consistently significant positive correlations for *T. crocea*.

One-way Analysis of Variance based on transformed metal concentrations ($\log_e$(concentration+1)) in the kidney of *T. maxima* from Campbell Island during the two seasons, from Campbell and Raine Islands during the pre-monsoon sampling period, and from Aureed and Campbell Islands during the post-monsoon sampling period are presented in Appendix Tables 55 to 57 respectively. Six metals, cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), manganese (Mn) and selenium (Se), displayed significant differences (p<=0.05) among seasons (Appendix Table 55). Seven metals, aluminium (Al), cadmium (Cd), chromium (Cr), mercury (Hg), manganese (Mn), nickel (Ni) and zinc (Zn), displayed significant differences (p<=0.05) among locations (Campbell and Raine Islands) during the pre-monsoon period (Appendix Table 56) while five, copper (Cu), manganese (Mn), strontium (Sr), uranium (U) and zinc (Zn), displayed significant differences (p<=0.05) among locations (Aureed and Campbell Islands) during the post-monsoon period (Appendix Table 57).

The concentrations (mg kg^{-1} dry weight) of all metals analysed from the three sampling stations (Aureed Island, Campbell and Raine Islands) within two seasons (pre- and post-monsoon) are presented in Appendix Table 58.

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*Results in this report for the metals silver (Ag), aluminium (Al), iron (Fe), manganese (Mn), strontium (Sr) and uranium (U) from Raine Island must not be cited. Please direct correspondence regarding these metals to G A Barry and G E Rayment, QDPI, Brisbane.

Seasonal pattern

Concentrations of the six metals (Co,Cr,Cu,Fe,Mn and Se) which were significantly different among seasons at Campbell Island are presented graphically in Figure 27. Five (Co,Cr,Cu,Fe and Mn) show higher concentrations during the post-monsoon sampling period while only one (Se) was highest during the pre-monsoon period. The concentrations of cadmium (Cd), nickel (Ni) and zinc (Zn) were also markedly higher during the post-monsoon period, although the differences among seasons were not statistically significant (see Appendix Table 55). Seasonal differences in metal concentrations cannot be attributed to changes in tissue weight as no difference in the relationship between shell length and tissue weight is evident among seasons (see Fig. 28).

Spatial patterns

Of the seven metals that displayed significant differences among locations during the pre-monsoon sampling period, four (Al,Cd,Mn and Zn) had highest concentrations at Campbell Island while three (Cr,Hg and Ni) had highest concentrations at Raine Island. These two patterns are presented graphically in Figures 29 and 30 respectively. While not statistically significant, the concentrations of arsenic, copper and iron were also substantially higher at Campbell Island during the pre-monsoon period.

Of the five metals that displayed significant differences among locations during the post-monsoon sampling period, three (Cu,U and Zn) had highest concentrations at Campbell Island while two (Mn and Sr) had highest concentrations at Aureed Island. These two patterns are presented graphically in Figures 31 and 32 respectively. The concentrations of silver, aluminium, arsenic and cadmium were also substantially higher at Campbell Island while nickel was higher at Aureed Island during the post-monsoon period, though these differences were not statistically significant.

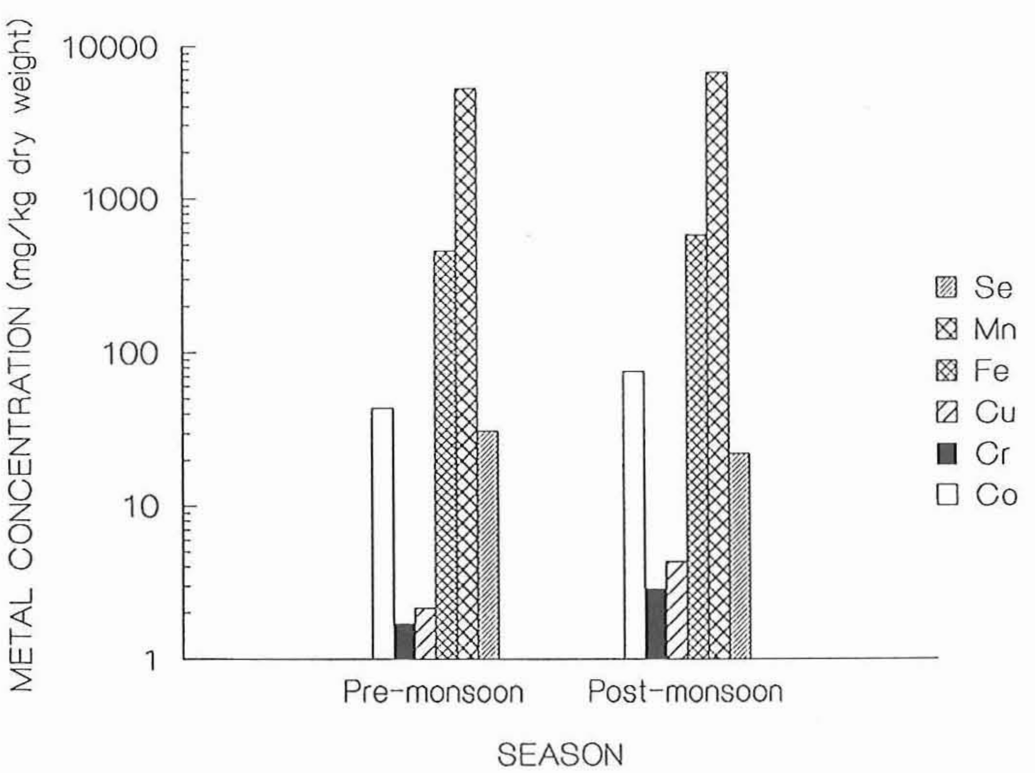

Figure 27. Cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), manganese (Mn) and selenium (Se) concentrations in the kidney of the clam *T. maxima* from Campbell Island during two seasons. The concentrations of all metals illustrated except selenium are significantly higher following the monsoon period.

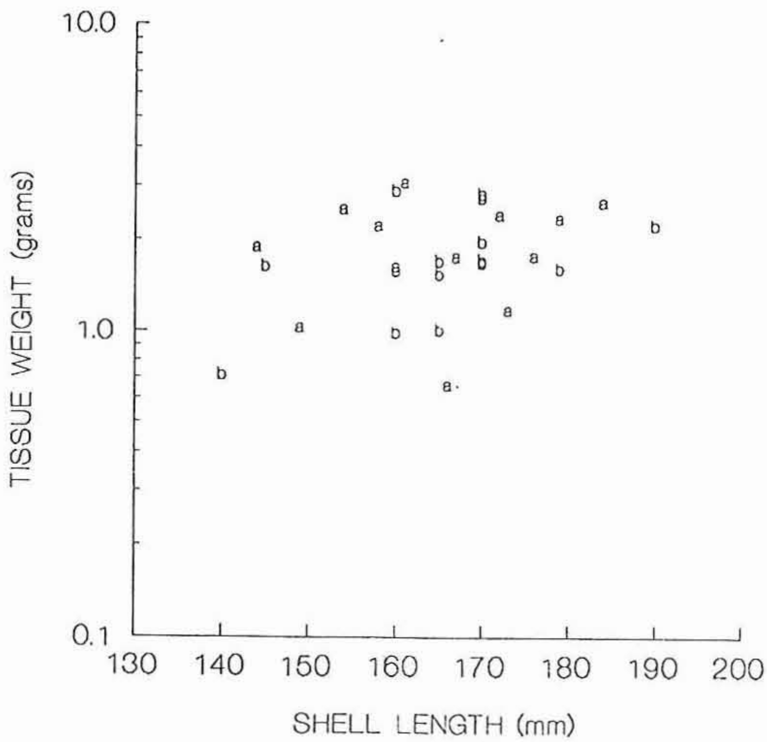

Figure 28. Relationship between shell length and kidney tissue dry weight in the clam *T. maxima* from Campbell Island. Samples are from the pre-monsoon (a) and post-monsoon (b) periods.

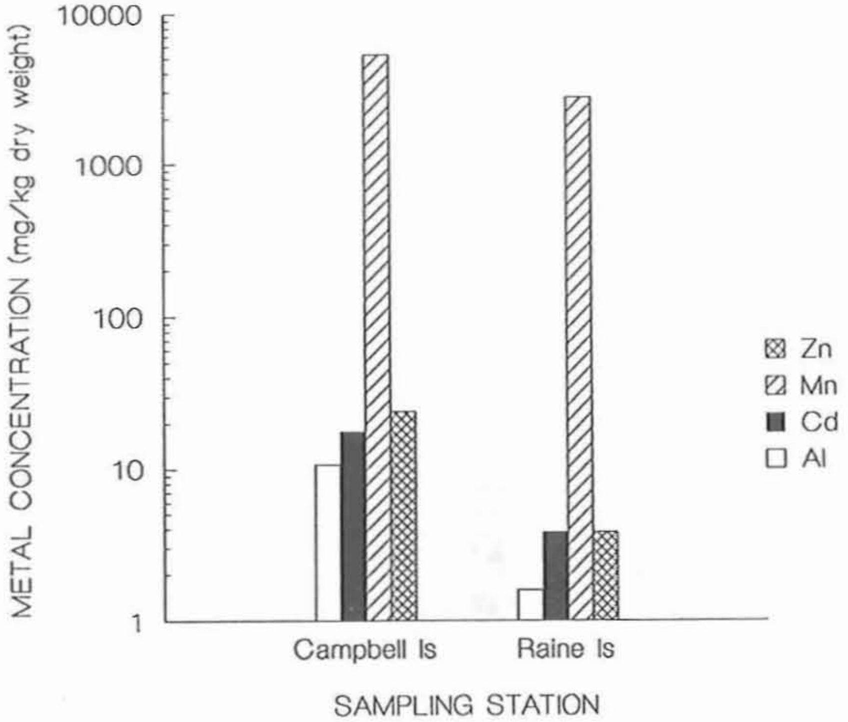

Figure 29. Aluminium (Al), cadmium (Cd), manganese (Mn) and zinc (Zn) concentrations in the kidney of the clam *T. maxima* from two locations during the pre-monsoon season. The concentrations of all metals illustrated are significantly higher at Campbell Island. Raine Island data provided by Barry and Rayment (1992).

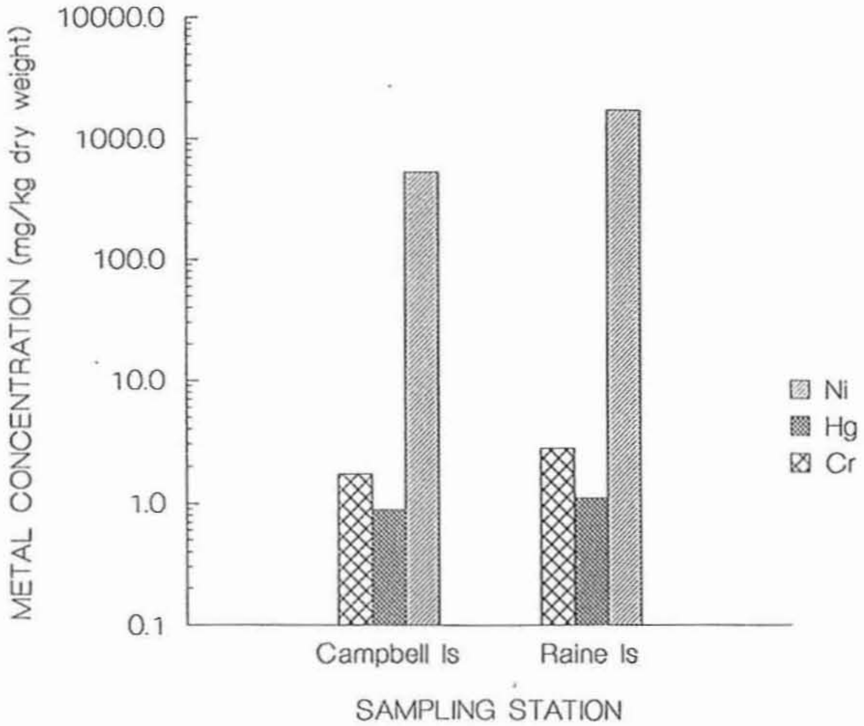

Figure 30. Chromium (Cr), mercury (Hg) and nickel (Ni) concentrations in the kidney of the clam *T. maxima* from two locations during the pre-monsoon season. The concentrations of all metals illustrated are significantly higher at Raine Island. Raine Island data provided by Barry and Rayment (1992).

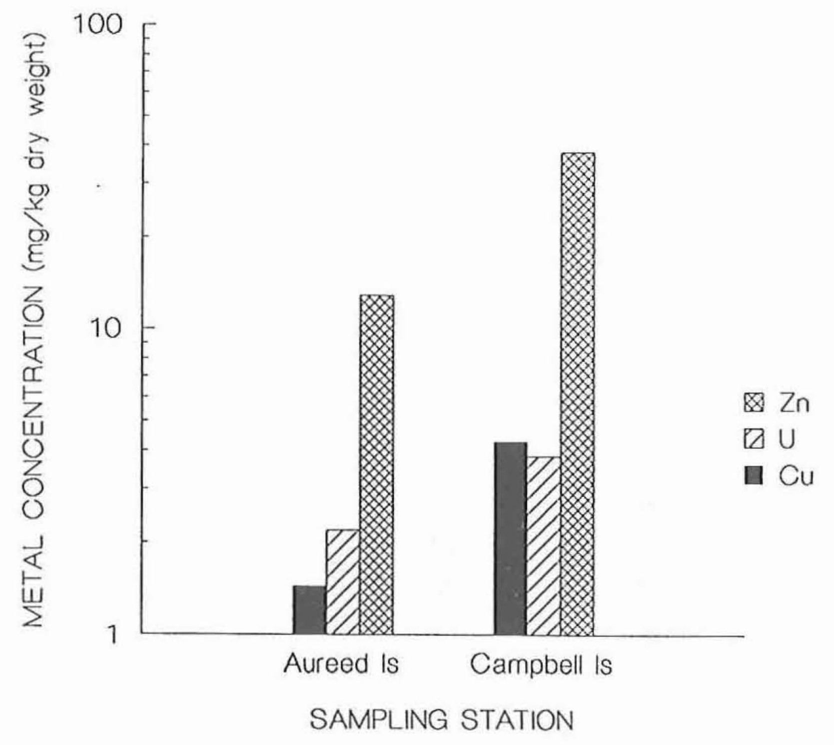

Figure 31. Copper (Cu), uranium (U) and zinc (Zn) concentrations in the kidney of the clam *T. maxima* from two locations during the post-monsoon season. The concentrations of all metals illustrated are significantly higher at Campbell Island.

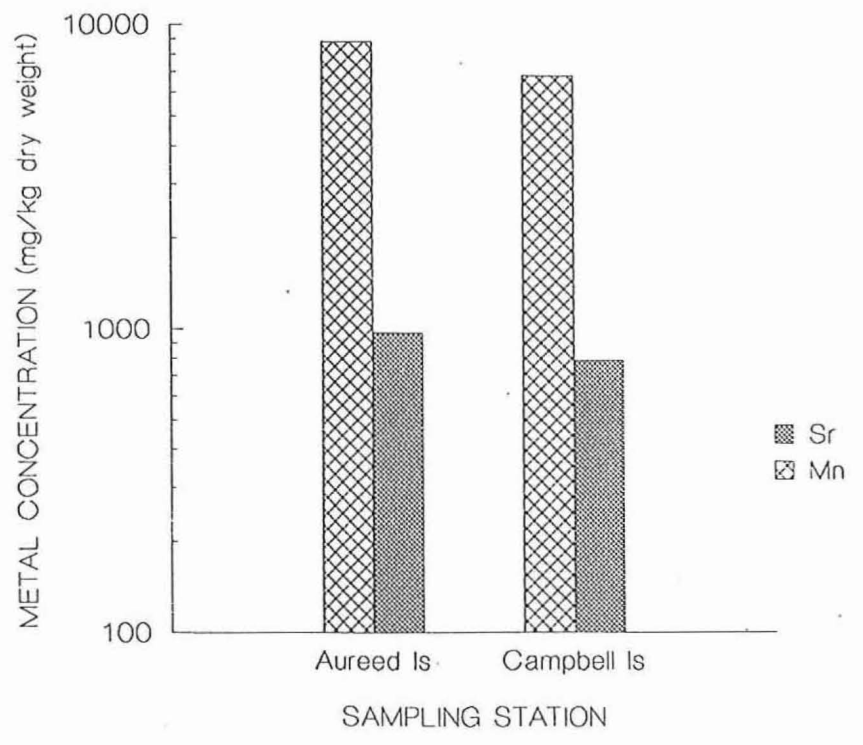

Figure 32. Strontium (Sr) and manganese (Mn) concentrations in the kidney of the clam *T. maxima* from two locations during the post-monsoon season. The concentrations of both metals are significantly higher at Aureed Island.

Regional variation

The concentrations of six metals (Cd,Cu,Hg,Ni,Pb and Zn) within the kidney of *T. maxima* from the present study are contrasted with results of other published studies from the Torres Strait, Great Barrier Reef and Coral Sea in Table 5. Only metals for which published data were available are listed. Note that there are two additional locations from the Torres Strait within the previously published studies: Murray and Yorke Islands. Both sets of samples were collected prior to the commencement of mining operations within the Fly River catchment.

Results show that the concentrations of cadmium, copper, mercury, nickel, lead and zinc from Aureed, Campbell and Raine Islands (this study) fall within the range of values that has been reported for similarly located (distance from the coast as nearshore, mid-shelf and off-shore) reefs within the GBR and Torres Strait. The concentrations of lead and zinc in samples from Orpheus and Magnetic Islands in the GBR, both of which are subjected to relatively minor inputs from anthropogenic sources, exceed those found in the Torres Strait. The concentration of copper in samples from Magnetic Island is also higher than that found in samples from the Torres Strait.

***Pinctata margaritifera* (black-lip pearl oyster)**

Shell length and tissue weight were positively correlated at all locations in both seasons and significantly different from zero ($p<=0.05$) except for Aureed Island during the post-monsoon season ($p=0.098$). There were no consistently strong correlations between shell length or tissue weight and metal concentrations.

Many combinations of metals displayed correlations which were significantly different from zero ($p<=0.05$) at individual locations within a season. Once again, these correlations were rarely consistently significant across all locations and seasons. The following relationships between logarithmically transformed metal concentrations were both strongly correlated and significantly different from zero across all locations and seasons: aluminium and iron; and arsenic and zinc.

One-way Analysis of Variance based on transformed metal concentrations ($\log_e$(concentration+1)) in the whole soft tissue of the oyster *P. margaritifera* from Aureed Island within two seasons is presented in Appendix Table 59. Eight metals, cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), mercury (Hg), manganese

Table 5. Regional and seasonal variation in selected trace metal concentrations (mg kg^{-1} dry weight) within the kidney tissue of *Tridacna maxima*. Data are mean and range (in parentheses). n = sample size. * Mercury concentrations in mg kg^{-1} wet weight. Sources = [1] Barry and Rayment (1992); [2] This study; [3] Denton & Heitz, 1991; [4] Burdon-Jones & Denton, 1984a; [5] Burdon-Jones & Denton, 1984b. TS = Torres Strait. ndp = no data presented.

Location	Collection Date	n	Cadmium	Copper	Mercury*	Nickel	Lead	Zinc
Raine Island [1] (GBR, offshore)	October,1991	21	3.81 (0.64-24.0)	1.54 (0.87-2.20)	0.325 (0.221-0.447)	1694 (740-3700)	10.1 (5.4-16.0)	3.8 (1.5-7.3)
Aureed Island [2] (TS, mid-shelf)	April,1992	15	20.70 (0.89-48.0)	1.45 (0.86-2.60)	0.719 (0.61-0.91)	970 (480-1400)	11.9 (6.8-17.0)	12.9 (2.0-57.0)
Campbell Island [2] (TS, mid-shelf)	October,1991	13	17.57 (1.0-67.0)	2.15 (1.2-4.0)	0.262 (0.036-0.387)	524 (290-680)	10.2 (6.7-14.0)	23.9 (3.1-89.0)
	April,1992	15	34.46 (5.8-65.0)	4.28 (1.4-13.0)	0.839 (0.47-1.10)	787 (410-1200)	11.9 (7.7-20.0)	38.0 (2.9-96.0)
Murray Island [3] (TS, offshore)	November, 1978	2	1.5 (1.0-2.1)	3.1 (2.3-4.1)	ndp	1986 (1536-2569)	7.8 (6.4-9.4)	2.2 (1.1-4.1)
York Island [3] (TS, mid-shelf)	November, 1978	2	70.9 (59.0-85.2)	2.5 (2.4-2.6)	ndp	789 (474-1313)	14.9 (8.7-25.4)	78.5 (65.2-94.4)
Flinders Reefs [3] (Coral Sea)	August,1981	10	4.52 (0.66-17.2)	3.16 (2.04-7.15)	0.59 (0.38-0.80)	ndp	15.3 (9.3-24.7)	2.41 (0.35-8.61)
Carter Reef [4] (GBR, offshore)	February, 1981	9	5.52 (1.29-13.40)	3.62 (2.14-4.51)	0.317 (0.276-0.358)	1605 (1011-2808)	10.18 (7.50-14.10)	ndp
Myrmidon Reef [3] (GBR, offshore)	August,1981	6	3.89 (0.41-19.9)	3.35 (2.58-4.18)	0.36 (0.27-0.49)	ndp	10.2 (8.3-12.4)	3.75 (1.09-6.25)

(Table 5 continued over)

Location	Collection Date	n	Cadmium	Copper	Mercury*	Nickel	Lead	Zinc
Heron Island [5] (GBR, offshore)	January,1981	12	7.19 (2.48-22.97)	3.21 (2.67-3.86)	0.446 (0.305-0.533)	703 (399-1353)	15.13 (9.03-26.76)	ndp
	April,1982	10	9.13 (2.91-50.62)	2.98 (1.92-4.45)	0.401 (0.317-0.489)	869 (597-1308)	10.88 (8.04-14.01)	5.8 (2.2-63.5)
	July,1982	10	9.07 (1.06-48.98)	3.87 (2.55-5.05)	0.369 (0.304-0.473)	1121 (869-1513)	11.64 (9.29-14.50)	5.0 (1.9-22.5)
	October,1982	10	2.07 (0.72-8.54)	3.16 (1.64-4.47)	0.354 (0.174-0.563)	1203 (839-1850)	10.54 (6.80-16.39)	3.2 1.7-5.7)
	January,1983	10	3.16 (0.69-13.17)	2.38 (1.39-9.19)	0.448 (0.280-0.581)	1308 (902-2532)	11.63 (9.04-14.50)	3.7 (1.2-9.1)
Lizard Island [4] (GBR, mid-shelf)	February, 1982	6	5.10 (0.54-14.73)	3.46 (2.78-4.14)	0.308 (0.179-0.521)	905.0 (428-1700)	14.28 (8.48-21.59)	19.76 (0.9-71.6)
	April,1982	10	10.20 (4.63-17.62)	3.78 (1.89-7.51)	0.362 (0.222-0.492)	1120 (469-1967)	21.45 (14.62-27.41)	81.6 (5.0-270.0)
	July,1982	10	17.43 (6.05-31.14)	3.71 (2.47-4.84)	0.393 (0.304-0.490)	718 (383-1196)	22.49 (15.75-38.10)	946.0 (643.0-1690).0
	October,1982	10	5.48 (0.98-16.97)	2.79 (1.72-5.64)	0.368 (0.288-0.591)	1163 (551-1904)	24.01 (13.34-34.51)	76.5 (3.9-401.0)
	January,1983	10	7.06 (2.24-14.06)	3.10 (2.54-4.51)	0.368 (0.254-0.598)	1250 (730-1755)	23.77 (14.26-38.63)	120.0 (20.9-586.0)
Linnet Reef [4] (GBR, nearshore)	February, 1981	6	17.12 (2.07-47.96)	3.39 (1.93-5.09)	0.506 (0.414-0.540)	920 (524-1594)	32.75 (24.57-44.86)	ndp

(Table 5 continued over)

Location	Collection Date	n	Cadmium	Copper	Mercury*	Nickel	Lead	Zinc
Orpheus Island [5] (GBR, nearshore)	April,1982	10	25.98 (8.56-70.15)	2.74 (1.71-6.90)	0.636 (0.382-0.878)	914 (629-1108)	43.98 (31.80-59.97)	231.0 (100.0-420.0)
	July,1982	10	26.43 (11.68-50.37)	5.35 (2.56-39.67)	0.844 (0.517-1.260)	1084 (641-1583)	46.06 (32.68-72.73)	301.0 (172.0-403.0)
	October,1982	10	15.30 (6.22-38.4)	3.95 (2.91-7.66)	0.824 (0.633-1.130)	1203 (629-1493)	60.28 (27.61-83.46)	215.0 (51.6-425.0)
	January,1983	10	26.11 (11.10-38.05)	5.50 (3.19-11.28)	0.664 (0.499-1.002)	980 (655-1699)	54.43 (37.45-79.91)	276.0 (142.0-454.0)
Magnetic Island [3] (GBR, nearshore)	October,1983	5	5.31 2.66-8.64	7.82 5.21-13.0	ndp	ndp	189.0 (160-251.0)	903.0 (443.0-1555.0)

(Mn), lead (Pb) and zinc (Zn) displayed statistically significant ($P<=0.05$) differences among seasons. Analysis of Variance based on metal concentrations from two locations, Aureed and Campbell Islands, during the pre-monsoon season is presented in Appendix Table 60. Only three metals, chromium (Cr), mercury (Hg) and selenium (Se), displayed significant differences among these two locations during the pre-monsoon period. Analysis of Variance based on metal concentrations from a different pair of locations, Aureed Island and Kokope Reef, during the post-monsoon season is presented in Appendix Table 61. During this period, four metals (cadmium (Cd), chromium (Cr), iron (Fe) and lead (Pb)) displayed statistically significant differences in concentration among locations.

The concentrations (mg kg^{-1} dry weight) of 13 metals from three sampling stations (Aureed Island, Campbell Island and Kokope Reef) during two seasons (pre- and post-monsoon) are presented in Appendix Table 62.

Seasonal patterns

Seven metals (Cd,Co,Cu,Hg,Mn,Pb and Zn) displayed significantly higher concentrations at Aureed Island during the pre-monsoon sampling period while only one (Cr) had significantly higher concentrations during the post-monsoon period (Appendix Table 62). These results are presented graphically in Figure 33. Arsenic (As) and selenium (Se) concentrations were also markedly higher during the pre-monsoon period at Aureed Island, but the differences were not statistically significant ($P>0.05$). Seasonal differences in metal concentrations cannot be attributed to changes in tissue weight as no difference in the relationship between shell length and tissue weight is evident among seasons (see Fig. 34).

Spatial patterns

Chromium (Cr), mercury (Hg) and selenium (Se) concentrations were all significantly higher in samples from Aureed Island than Campbell Island during pre-monsoon season (Appendix Table 62). These results are presented graphically in Figure 35. During the post-monsoon season, only chromium was elevated in samples from Aureed Island while cadmium (Cd), iron (Fe) and lead (Pb) were higher in samples from Kokope Reef. This post-monsoon pattern is presented in Figure 36. Nickel (Ni) concentrations were also markedly higher in samples from Aureed Island than Kokope Reef while the reverse was true for aluminium (Al) and manganese (Mn), but these differences were not statistically significant ($P>0.05$).

Regional variation

The concentrations of six metals (Cd,Cu,Hg,Ni,Pb and Zn) within the whole soft tissue of *P. margaritifera* from the present study are contrasted with the results of another published study (Burdon-Jones & Denton, 1984a) from the Great Barrier Reef and Coral Sea in Table 6. Only metals for which published data were available are listed.

Results show that the concentrations of copper, mercury, nickel, lead and zinc in samples from Aureed and Campbell Islands, and Kokope Reef (this study) fall within the range of values that has been reported for similarly located (nearshore or mid-shelf) reefs within the GBR. The concentrations of lead and zinc from Orpheus Island exceed those found in the Torres Strait. This was also the case for *T. crocea* (lead) and *T. maxima* (lead and zinc). Only cadmium concentrations appear to be elevated in the Torres Strait when compared to similarly located reefs within the GBR. It is interesting that cadmium concentration, only in a single individual, from Flinders Reef in the Coral Sea is comparable with mean values in samples from the Torres Strait.

Table 6. Regional and seasonal variation in selected trace metal concentrations (mg kg^{-1} dry weight) within the whole soft tissue of the oyster *P. margaritifera*. Data are mean and range (in parentheses). n = sample size. * Mercury concentrations in mg kg^{-1} wet weight. Sources = [1] This study; [2] Burdon-Jones & Denton, 1984a. TS = Torres Strait. ndp = no data presented.

Location	Collection Date	n	Cadmium	Copper	Mercury*	Nickel	Lead	Zinc
Aureed Island [1] (TS, mid-shelf)	October,1991	15	10.59 (5.9-19.6)	5.49 (3.1-9.5)	0.017 (0.007-0.035)	3.23 (1.7-4.9)	0.205 (0.15-0.35)	294.3 (100-870)
	April,1992	15	7.24 (4.7-12.0)	3.88 (2.8-4.7)	0.006 (0.003-0.010)	2.99 (1.1-5.9)	0.097 (0.06-0.12)	157.8 (73-325)
Campbell Island [1] (TS, mid-shelf)	October,1991	15	11.33 (5.1-17.8)	5.16 (3.5-6.9)	0.006 (0.004-0.011)	2.56 (0.7-6.5)	0.191 (0.10-0.90)	329.8 (82-965)
Kokope Reef [1] (TS, nearshore)	April,1992	15	9.27 (4.4-15.0)	3.77 (2.5-4.7)	0.007 (0.006-0.009)	2.03 (1.3-3.3)	0.162 (0.07-0.28)	228.1 (71-442)
Flinders Reefs [2] (Coral Sea)	September, 1981	1	9.77	4.54	0.018	9.77	1.41	135
Lizard Island [2] (GBR, mid-shelf)	December, 1981	2	3.67 (1.62-5.72)	4.97 (4.04-5.89)	0.013 (0.013-0.013)	3.67 (1.6-5.7)	ndp (<0.6-<0.75)	74 (72-76)
Linnet Reef [2] (GBR, nearshore)	February, 1981	2	2.91 (1.34-4.47)	4.59 (3.89-5.28)	0.008	2.91 (1.34-4.47)	ndp (<0.66-<0.76)	499 (494-505)
Orpheus Island [2] (GBR, nearshore)	December, 1980	1	3.67	4.44	0.018	3.74	1.24	1097

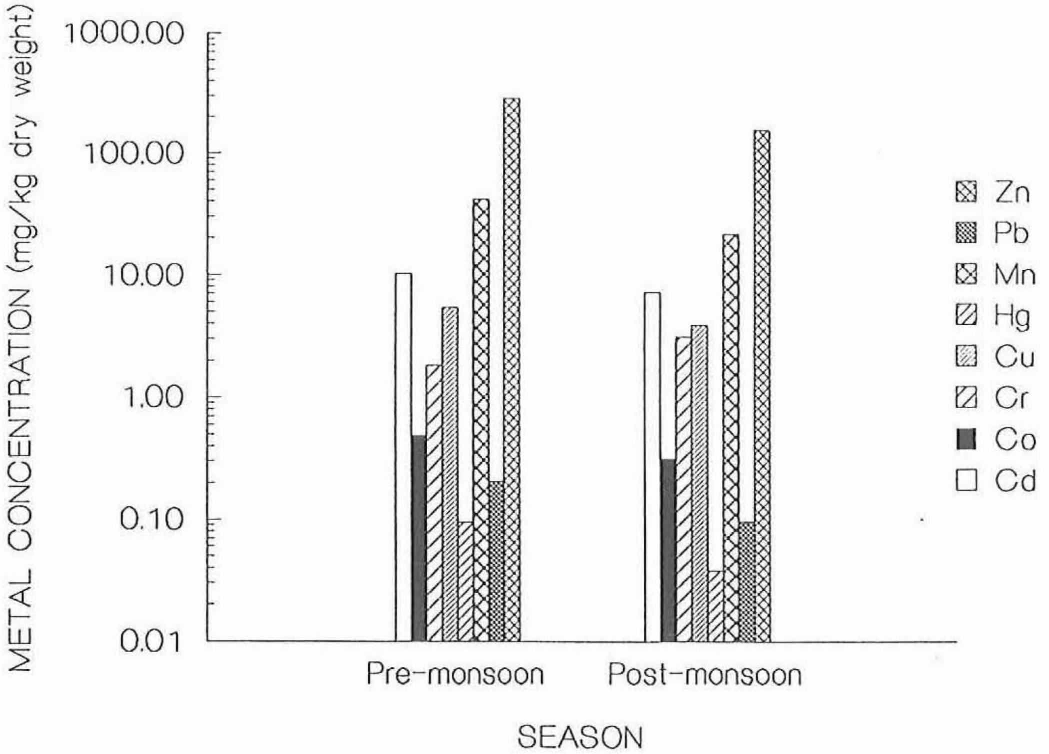

Figure 33. Cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), mercury (Hg), manganese (Mn), lead (Pb) and zinc (Zn) concentrations in the whole soft tissue of the oyster *P. margaritifera* from Aureed Island during two seasons. The concentrations of all metals were significantly different among seasons. Only chromium concentration was highest during the post-monsoon season.

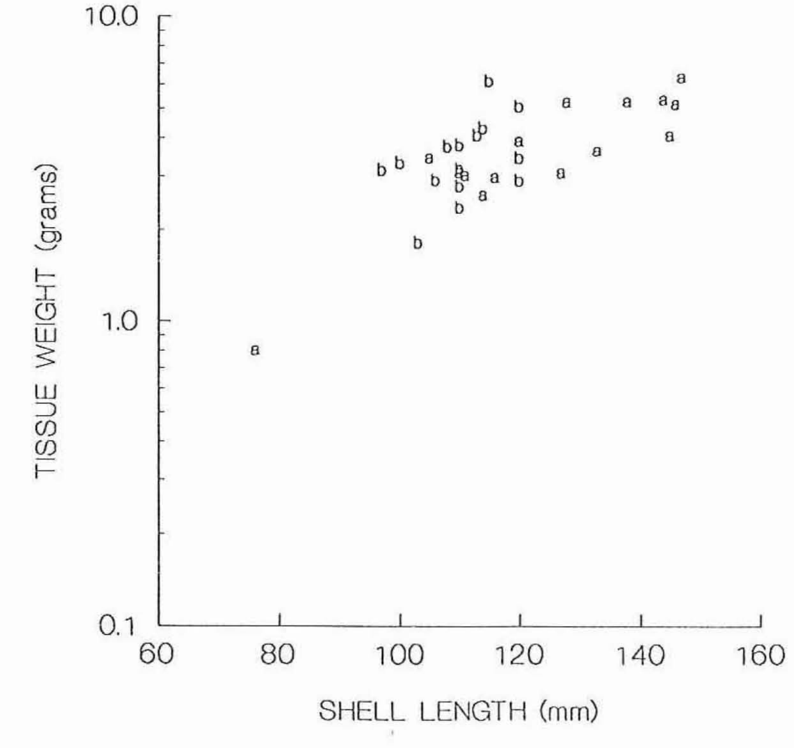

Figure 34. Relationship between shell length and whole soft tissue dry weight in the oyster *P. margaritifera* from Aureed Island. Samples are from the pre-monsoon (a) and post-monsoon (b) periods.

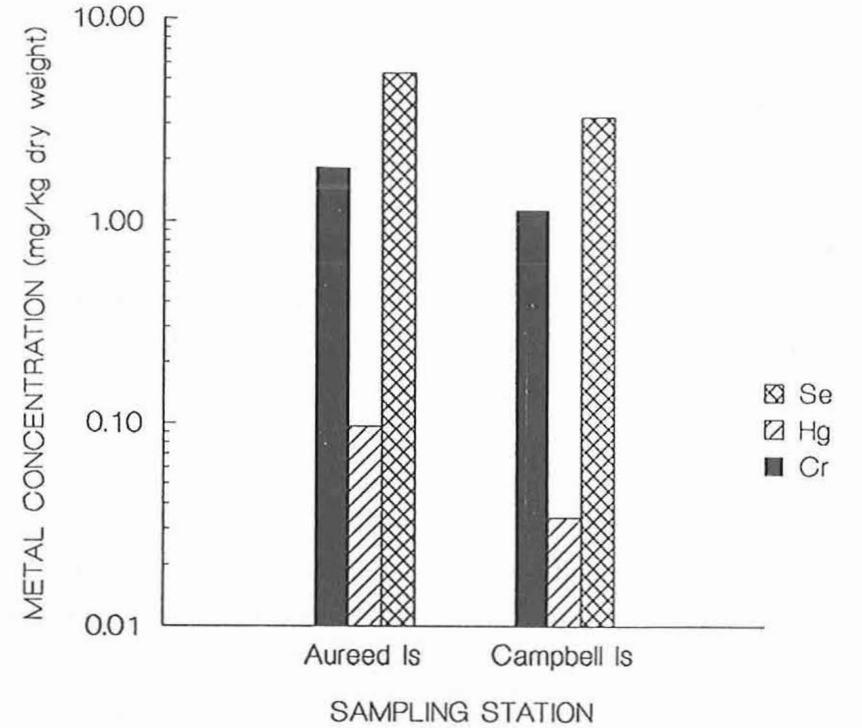

Figure 35. Chromium (Cr), mercury (Hg) and selenium (Se) concentrations in the whole soft tissue of the oyster *P. margaritifera* from two locations during the pre-monsoon season. The concentrations of all three metals were significantly higher at Aureed Island.

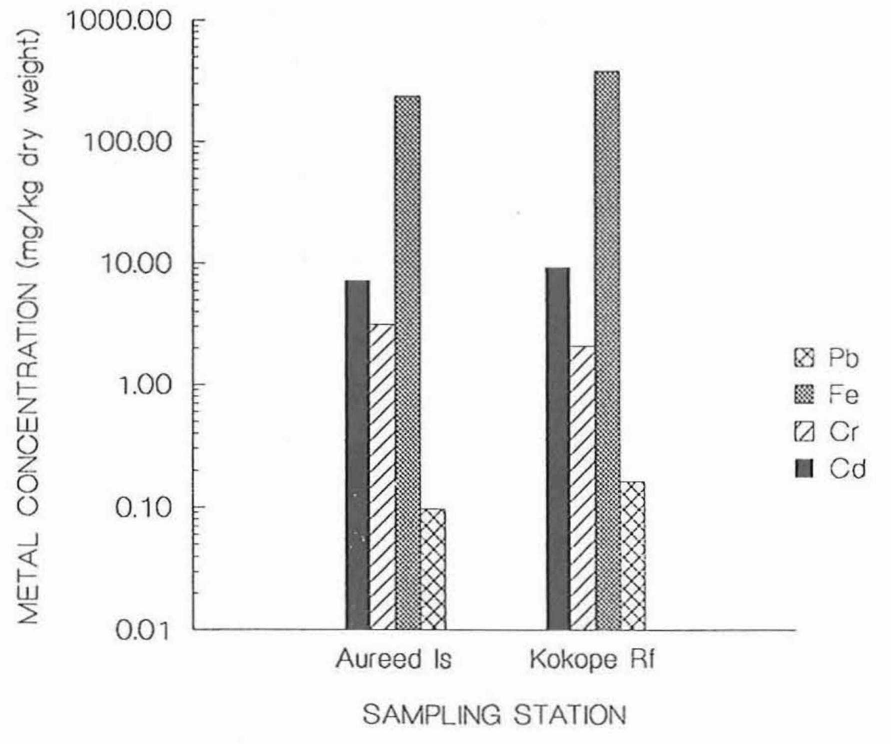

Figure 36. Cadmium (Cd), chromium (Cr), iron (Fe) and lead (Pb) concentrations in the whole soft tissue of the oyster *P. margaritifera* from two locations during the post-monsoon season. The concentrations of all four metals were significantly different among locations. Only chromium concentration was highest at Aureed Island.

Hyotissa hyotis (coxcombe or zig-zag oyster)

Shell length and tissue weight were positively, but poorly, correlated at all combinations of location and season except for Kokope Reef during the pre-monsoon period. Only at this combination of reef and season was the correlation significantly different from zero ($p<=0.05$). There were no consistently strong correlations between shell length or tissue weight and metal concentrations.

Many combinations of metals displayed correlations which were significantly different from zero ($p<=0.05$) at individual locations within a season. Once again, these correlations were rarely consistently significant across all locations and seasons. Only the relationships between logarithmically transformed aluminium and iron concentrations were both strongly correlated and significantly different from zero across all locations and seasons.

Two-way Analysis of Variance based on transformed metal concentrations ($\log_e$(concentration+1)) in the whole soft tissue of *H. hyotis* are presented in Appendix Table 63. Nine metals, aluminium (Al), cadmium (Cd), cobalt (Co), iron (Fe), mercury (Hg), nickel (Ni), lead (Pb), selenium (Se) and zinc (Zn), displayed no statistically significant differences ($p>0.05$) among seasons or sampling stations. Three metals, chromium (Cr), copper (Cu) and manganese (Mn), showed significant differences among seasons while only two, chromium and manganese, displayed significant differences among locations. Manganese displayed a statistically significant interaction between season and station.

The concentrations (mg kg^{-1} dry weight) of all 13 metals from the two sampling stations (Aureed Island and Kokope Reef) within two seasons (pre- and post-monsoon) are presented in Appendix Table 64.

Seasonal patterns

Copper (Cu) concentration was significantly higher ($p<=0.05$) across both sampling stations during the pre-monsoon period while manganese was elevated at Kokope Reef only during the same season. There was no significant seasonal variation in manganese concentration at Aureed Island. In contrast, the concentration of chromium (Cr) was significantly higher across both sampling stations during the post-monsoon period. These patterns are presented for Kokope Reef in Figure 37. Although the size of individuals collected during the post-monsoon season was substantially greater than during the pre-monsoon period, there is no evidence that seasonal variation in metal concentrations can be attributed to a change in tissue weight (see Fig. 38 for Kokope Reef).

Spatial patterns

Arsenic and manganese concentrations were both significantly higher at Kokope Reef while chromium concentration was higher in samples from Aureed Island. Manganese concentrations varied among locations only during the pre-monsoon period. These patterns are presented graphically for the pre-monsoon period in Figure 39.

Regional variation

The concentrations of six metals (Cd,Cu,Hg,Ni,Pb and Zn) within the whole soft tissue of *H. hyotis* from the present study are contrasted with the results of another published study (Burdon-Jones & Denton, 1984a) from the Great Barrier Reef in Table 7. Only metals for which published data were available are listed.

Results show that the concentrations of all six metals in samples from Aureed Island and Kokope Reef (this study) generally fall within the range of values that has been reported for similarly located (nearshore or mid-shelf) reefs within the GBR. The mean concentrations of copper from Kokope Reef during the pre-monsoon season and cadmium from Aureed Island appear to be slightly elevated when compared to GBR locations.

Chama plinthota (jewel-box oyster)

Shell length and tissue weight were positively correlated and significantly different from zero ($p<=0.05$) at Aureed Island during both seasons. However, this was not the case at Kokope Reef where shell length and tissue weight were poorly correlated. There were no consistently strong correlations between shell length or tissue weight and metal concentrations.

Many combinations of metals displayed correlations which were significantly different from zero ($p<=0.05$) at individual locations within a season. Once again, these correlations were rarely consistently significant across all locations and seasons. The

Table 7. Regional and seasonal variation in selected trace metal concentrations (mg kg^{-1} dry weight) within the whole soft tissue of the oyster *H. hyotis*. Data are mean and range (in parentheses). n = sample size. * Mercury concentrations in mg kg^{-1} wet weight. Sources = [1] This study; [2] Burdon-Jones & Denton, 1984a. TS = Torres Strait. ndp = no data presented. bdl = below detection limit.

Location	Collection Date	n	Cadmium	Copper	Mercury*	Nickel	Lead	Zinc
Aureed Island [1]	October,1991	15	2.04	8.41	0.007	0.72	<0.30	539.3
(TS, mid-shelf)			(0.50-3.6)	(2.7-13.0)	(0.004-0.012)	(0.3-1.8)	bdl	(210-945)
	April,1992	15	2.12	6.55	0.005	0.81	0.10	325.5
			(1.30-3.7)	(2.8-16.0)	(0.004-0.012)	(0.6-1.5)	(0.07-0.12)	(79-1420)
Kokope Reef [1]	October,1991	15	1.38	10.30	0.008	0.93	0.49	799.4
(TS, nearshore)			(0.78-2.6)	(3.0-19.0)	(0.002-0.020)	(0.5-4.1)	(0.12-3.6)	(327-1800)
	April,1992	15	1.97	4.68	0.005	0.66	0.13	481.5
			(0.91-3.3)	(2.7-7.6)	(0.004-0.016)	(0.4-1.3)	(0.07-0.24)	(193-1070)
Lizard Island [2]	February,	3	1.37	5.55	0.008	1.37	ndp	268
(GBR, mid-shelf)	1981		(0.62-2.33)	(4.19-8.27)	(0.006-0.011)	(0.62-2.33)	(<0.6-<0.75)	(148-241)
Orpheus Island [2]	December,	9	0.72	6.24	0.012	0.72	ndp	799
(GBR, nearshore)	1980		(0.63-0.85)	(4.77-8.06)	(0.008-0.014)	(0.63-0.85)	(<0.51-4.49)	(660-1425)

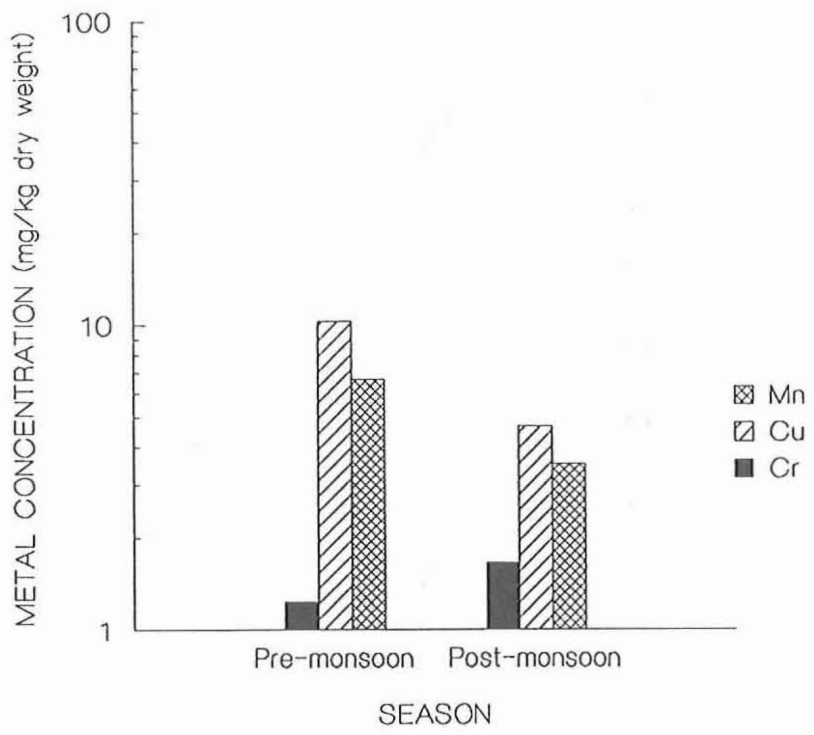

Figure 37. Chromium (Cr), copper (Cu) and manganese (Mn) concentrations in the whole soft tissue of the oyster *H. hyotis* from Kokope Reef during two seasons. The concentrations of all three metals were significantly different among seasons. Only chromium concentration is highest during the post-monsoon period

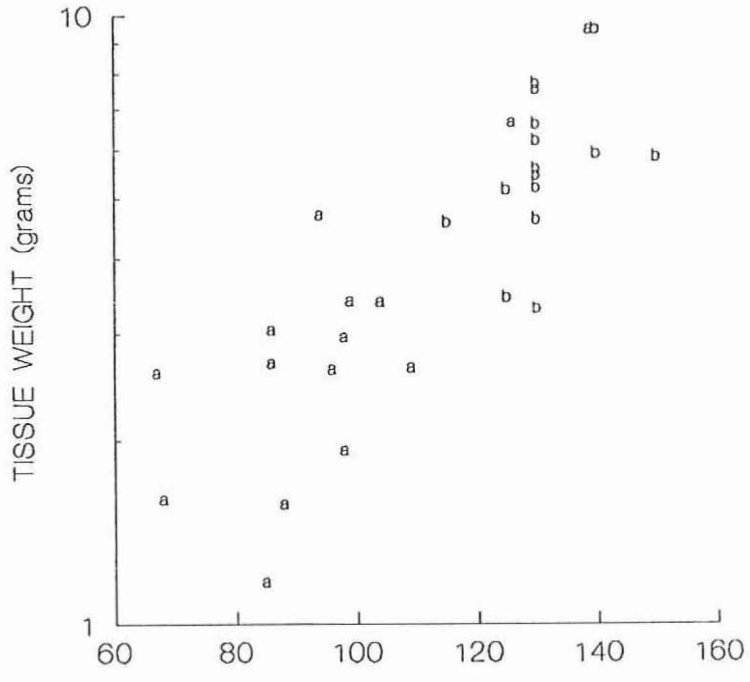

Figure 38. Relationship between shell length and whole soft tissue dry weight in the oyster *H. hyotis* from Kokope Reef. Samples are from the pre-monsoon (a) and post-monsoon (b) periods.

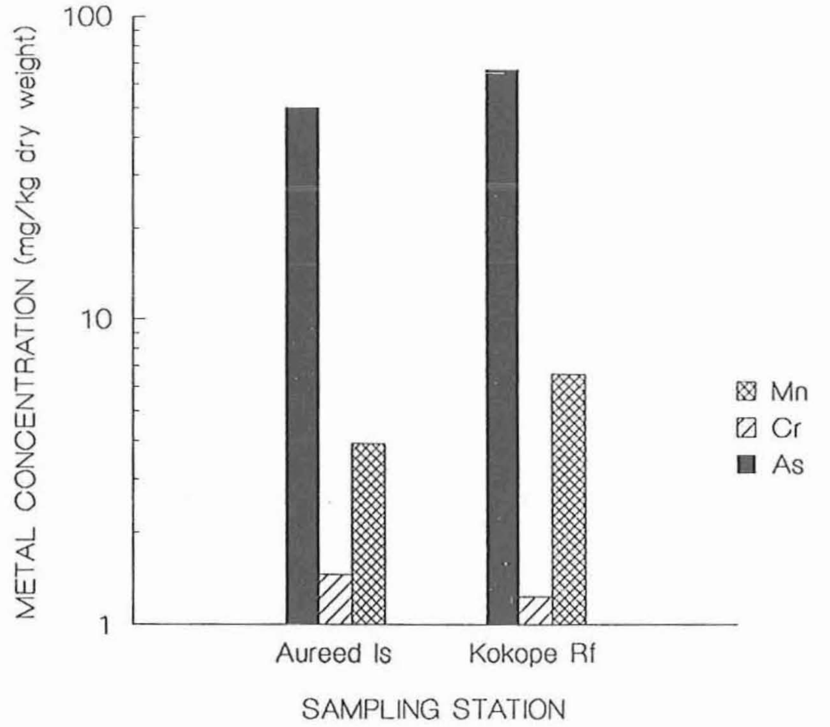

Figure 39. Arsenic (As), chromium (Cr) and manganese (Mn) concentrations in the whole soft tissue of the oyster *H. hyotis* from two locations during the pre-monsoon season. The concentrations of all three metals were significantly different among locations. Only chromium concentration was highest at Aureed Island.

following relationships between logarithmically transformed metal concentrations were both strongly correlated and significantly different from zero across all locations and seasons: arsenic and nickel; and cobalt and nickel.

One-way Analysis of Variance based on transformed metal concentrations ($\log_e$(concentration+1)) in the whole soft tissue of *C. plinthota* within two seasons is presented in Appendix Table 65. Eleven metals, aluminium (Al), arsenic (As), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), nickel (Ni), lead (Pb), selenium (Se) and zinc (Zn), displayed no statistically significant differences ($p>0.05$) among seasons. Only two metals, mercury (Hg) and manganese (Mn), showed significant differences ($p<=0.05$) among seasons. Analysis of Variance based on metal concentrations from two locations, Aureed Island and Kokope Reef, during the post-monsoon season is presented in Appendix Table 66. Only one metal, chromium, showed significant differences among the two locations.

The concentrations (mg kg^{-1} dry weight) of all 13 metals from the two sampling stations (Aureed Island and Kokope Reef) within two seasons (pre- and post-monsoon) are presented in Appendix Table 67.

Seasonal patterns

Mercury (Hg) and manganese (Mn) concentrations in samples from Aureed Island were significantly higher ($p<=0.05$) during the pre-monsoon period (Appendix Table 67). This pattern is presented graphically in Figure 40. In contrast, aluminium concentration in samples from Aureed Island was markedly higher during the post-monsoon period, but this difference was not statistically significant ($p>0.05$). Seasonal differences in metal concentrations cannot be attributed to changes in tissue weight as no difference in the relationship between shell length and tissue weight is evident (see Fig. 41).

Spatial patterns

The concentration of chromium in samples from Kokope reef was significantly higher than in samples from Aureed Island. Mercury and manganese concentrations were also markedly higher at Kokope Reef but these differences were not statistically significant ($p>0.05$).

Regional variation

There are no other known studies that have measured trace metal concentrations in the soft tissue of *C. plinthota*.

Trochus niloticus* (trochus)

Shell length and tissue weight were positively correlated at all combinations of location and season. However this relationship was only significantly different from zero ($p<=0.05$) at Aureed and Raine Islands during the pre-monsoon season and Kokope Reef during the post-monsoon period. There were no consistently strong correlations between shell length or tissue weight and metal concentrations.

Many combinations of metals displayed correlations which were significantly different from zero ($p<=0.05$) at individual locations within a season. However, none were consistently significant across all locations and seasons.

* Results in this report for the metals silver (Ag). aluminium (Al), iron (Fe), manganese (Mn), strontium (Sr) and uranium (U) from Raine Island must not be cited. Please direct correspondence regarding these metals to G A Barry and G E Rayment, QDPI, Brisbane.

One-way Analysis of Variance based on transformed metal concentrations ($\log_e$(concentration+1)) in the muscle tissue of *T. niloticus* from Aureed Island within two seasons is presented in Appendix Table 68. Ten metals, aluminium (Al), arsenic (As), cadmium (Cd), cobalt (Co), copper (Cu), mercury (Hg), manganese (Mn), nickel (Ni), selenium (Se) and zinc (Zn), displayed no statistically significant differences ($p>0.05$) among seasons. Only three metals, chromium (Cr), iron (Fe) and lead (Pb), showed significant differences ($p<=0.05$) among seasons. Analysis of Variance based on metal concentrations from four locations, Aureed Island, Dungeness Reef, Kokope Reef and Raine Island, during the pre-monsoon season is presented in Appendix Table 69. The concentrations of four metals, cobalt (Co), manganese (Mn), nickel (Ni) and zinc (Zn), varied significantly among the four locations. Analysis of Variance based on metal concentrations from only two locations, Aureed Island and Kokope Reef, during the post-monsoon season is presented in Table Appendix 70. During this period, the concentrations of aluminium (Al), cadmium (Cd), cobalt (Co), mercury (Hg), manganese (Mn), lead (Pb) and zinc (Zn) varied significantly among the two locations.

The concentrations (mg kg^{-1} dry weight) of all 13 metals from the two sampling stations (Aureed Island and Kokope Reef) within two seasons (pre- and post-monsoon) are presented in Appendix Tables 71 to 83.

Seasonal patterns

Iron and lead concentrations were significantly higher at Aureed Island during the pre-monsoon season while chromium was significantly higher during the post-monsoon period (Appendix Tables 77,81 and 75 respectively). These patterns are presented graphically in Figure 42. Cobalt concentrations were also markedly higher during the pre-monsoon period while selenium was higher during the post-monsoon season, but these differences were not statistically significant ($p>0.05$). The very small sample size from Kokope Reef during the pre-monsoon period precludes drawing any conclusions based on the limited data. The relationship between shell length and tissue weight is presented in Figure 43. Seasonal differences in metal concentrations do not appear to be attributable to changes in tissue weight. However, the correlation between shell length and tissue weight is very poor, not significantly different from zero and the size of samples much smaller during the post-monsoon season.

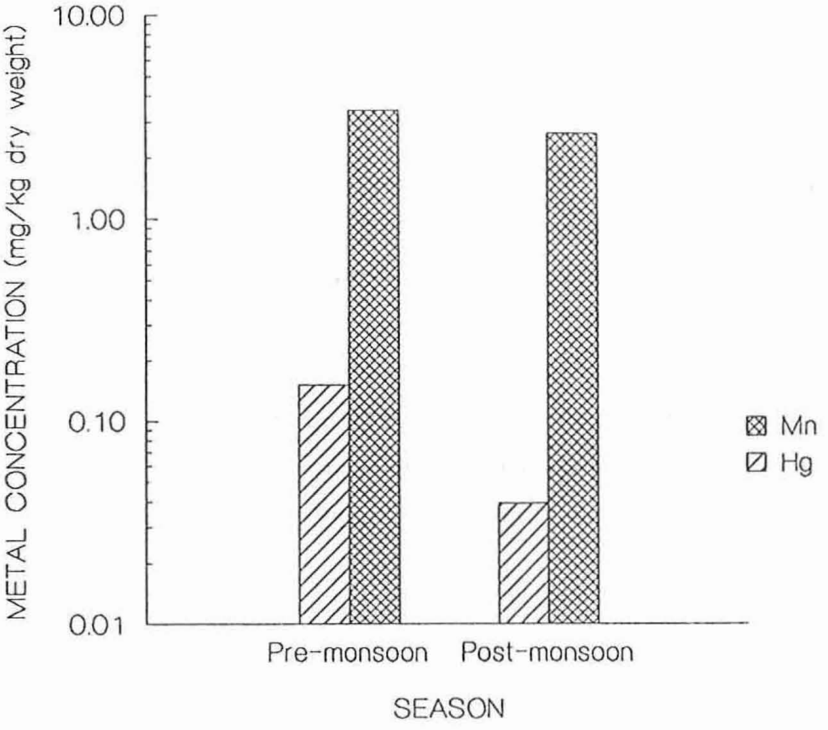

Figure 40. Mercury (Hg) and manganese (Mn) concentrations in the whole soft tissue of the oyster *C. plinthota* from Aureed Island during two seasons. The concentrations of both metals were significantly higher during the pre-monsoon period.

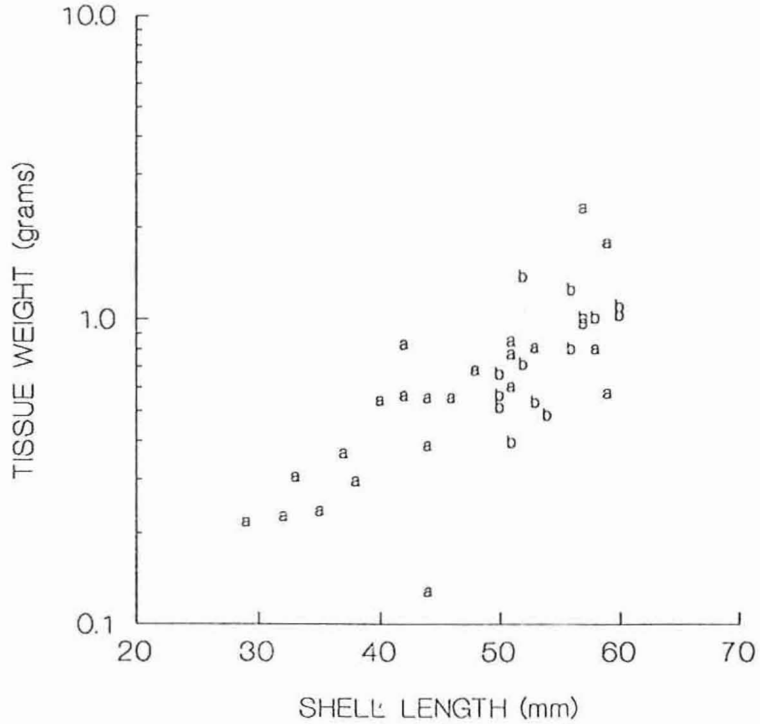

Figure 41. Relationship between shell length and whole soft tissue dry weight in the oyster *C. plinthota* from Aureed Island. Samples are from the pre-monsoon (a) and post-monsoon (b) seasons.

Spatial patterns

During the pre-monsoon season, the concentrations of cobalt, manganese and nickel were highest at Kokope Reef while zinc was highest at Dungeness Reef. The concentrations of these four metals at all four sampling locations are presented graphically in Figure 44. Note that the sample size from Kokope Reef is particularly small (n=2). Tukey's HSD test indicated that the differences between individual locations for cobalt were not significant ($p>0.05$). Copper and selenium concentrations were also highest at Kokope Reef while aluminium was highest at Dungeness followed by Kokope, but these differences were not statistically significant.

During the post-monsoon season, aluminium, cadmium, cobalt, mercury, manganese, lead and zinc were all significantly higher in samples from Kokope Reef. These results are presented in Figure 45. Nickel concentrations were also markedly higher at Kokope Reef, but these differences were not statistically significant.

Regional variation

There are no other known studies that have measured trace metal concentrations in the soft tissue of *T. niloticus*.

Strombus luhuanus **(red-lipped stromb)**

Shell length and tissue weight were positively, although poorly, correlated at all combinations of location and season but not at the back-reef habitat. At no combination of location, season and habitat was this relationship significantly different from zero ($p<=0.05$). There were no consistently strong correlations between shell length or tissue weight and metal concentrations.

Many combinations of metals displayed correlations which were significantly different from zero ($p<=0.05$) at individual locations within a season. However, none were consistently significant across all locations and seasons.

Two-way Analysis of Variance based on transformed metal concentrations ($\log_e$(concentration+1)) in the muscle tissue of *S. luhuanus* from two locations (Aureed and Campbell Islands) within two seasons (pre- and post-monsoon) is presented in Appendix Table 84. Ten metals, aluminium (Al), arsenic (As), cadmium (Cd), cobalt (Co), copper (Cu), manganese (Mn), nickel (Ni), lead (Pb), selenium (Se) and zinc

(Zn), displayed no statistically significant differences ($p>0.05$) among seasons or locations. Two metals, chromium (Cr) and iron (Fe) showed significant differences ($p<=0.05$) among seasons while only mercury (Hg) displayed a significant difference among locations. Analysis of Variance based on metal concentrations from two habitats (fore- and back-reef) at Aureed Island is presented in Appendix Table 85. Only cadmium (Cd) concentrations varied significantly ($p<=0.05$) among habitats.

The concentrations (mg kg^{-1} dry weight) of 13 metals from all combinations of season, sampling station and habitat are presented in Appendix Table 86.

Seasonal patterns

Both chromium (Cr) and iron (Fe) concentrations were highest during the pre-monsoon period at Aureed and Campbell Islands (Appendix Table 86). This pattern is presented graphically in Figure 46 for Campbell Island. In contrast, the concentration of lead (Pb) was markedly higher during the post-monsoon season, but this difference was not statistically significant ($p>0.05$). As the relationship between shell size and tissue weight was not significantly different from zero it is not possible to assess whether these differences could result form seasonal changes in biomass. This is unlikely, however, when the soft tissue that has been analysed does not contain gonad as in this case.

Spatial patterns

Mercury (Hg) concentrations were highest at Aureed Island, particularly during the post-monsoon period. Samples collected from fore-reef habitat at Aureed Island were significantly higher in cadmium (Cd) than those from the back-reef habitat. Otherwise, metal concentrations did not vary significantly among locations or habitats.

Regional variation

There are no other known studies that have measured trace metal concentrations in the soft tissue of S. *luhuanus*.

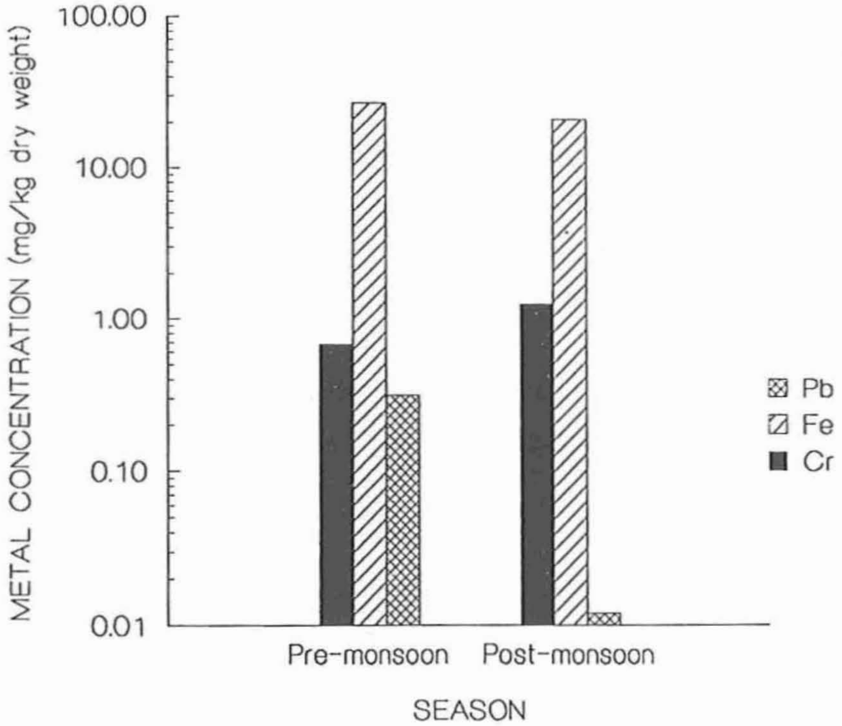

Figure 42. Chromium (Cr), iron (Fe) and lead (Pb) concentrations in the muscle tissue of the gastropod mollusc *T. niloticus* from Aureed Island during two seasons. The concentrations of all three metals were significantly different among seasons. Only chromium concentration was higher during the post-monsoon period.

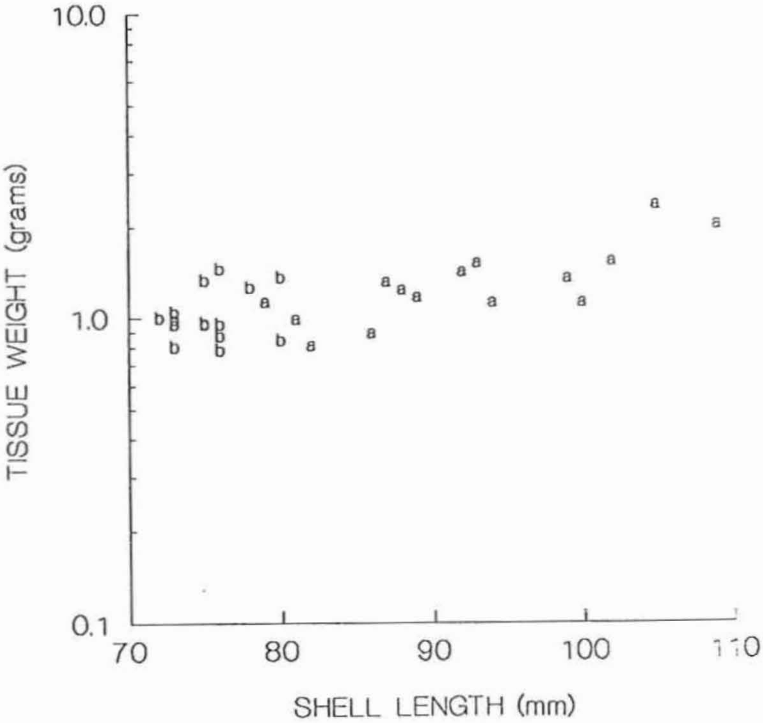

Figure 43. Relationship between shell length and muscle tissue dry weight in the gastropod mollusc *T. niloticus* from Aureed Island. Samples are from the pre-monsoon (a) and post-monsoon (b) periods.

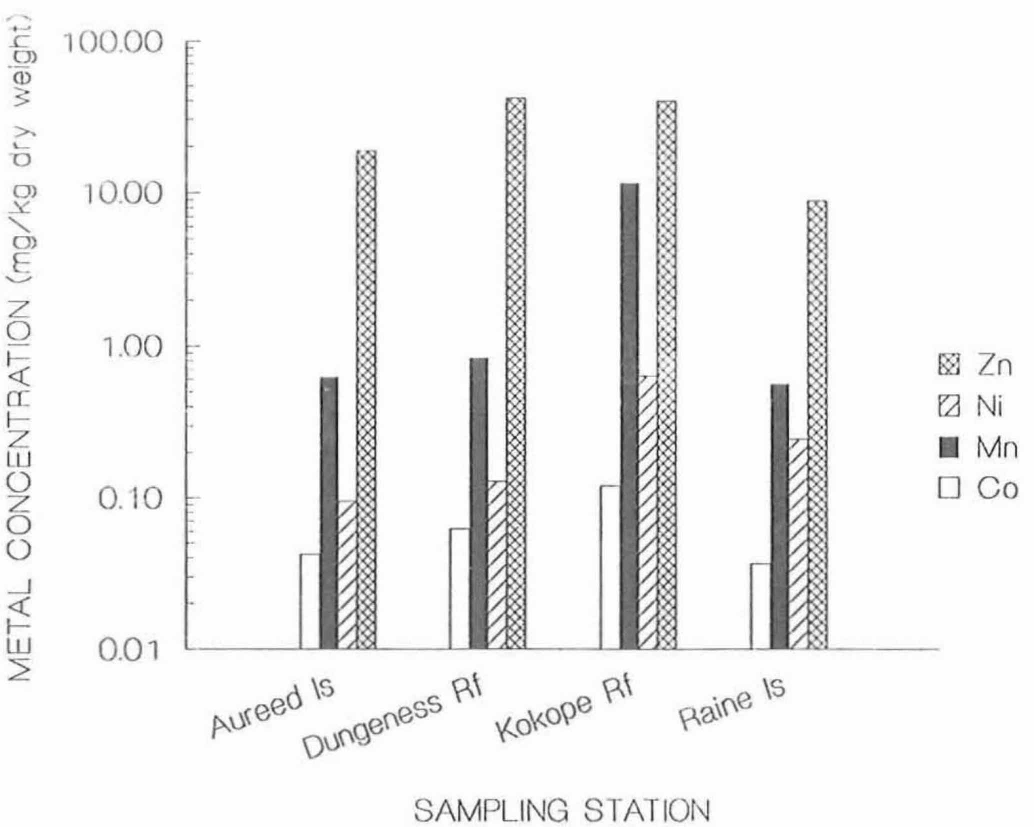

Figure 44. Cobalt (Co), manganese (Mn), nickel (Ni) and zinc (Zn) concentrations in muscle tissue of the gastropod mollusc *T. niloticus* from four locations during the pre-monsoon season. The concentrations of all four metals were significantly different among locations. Raine Island data provided by Barry and Rayment (1992).

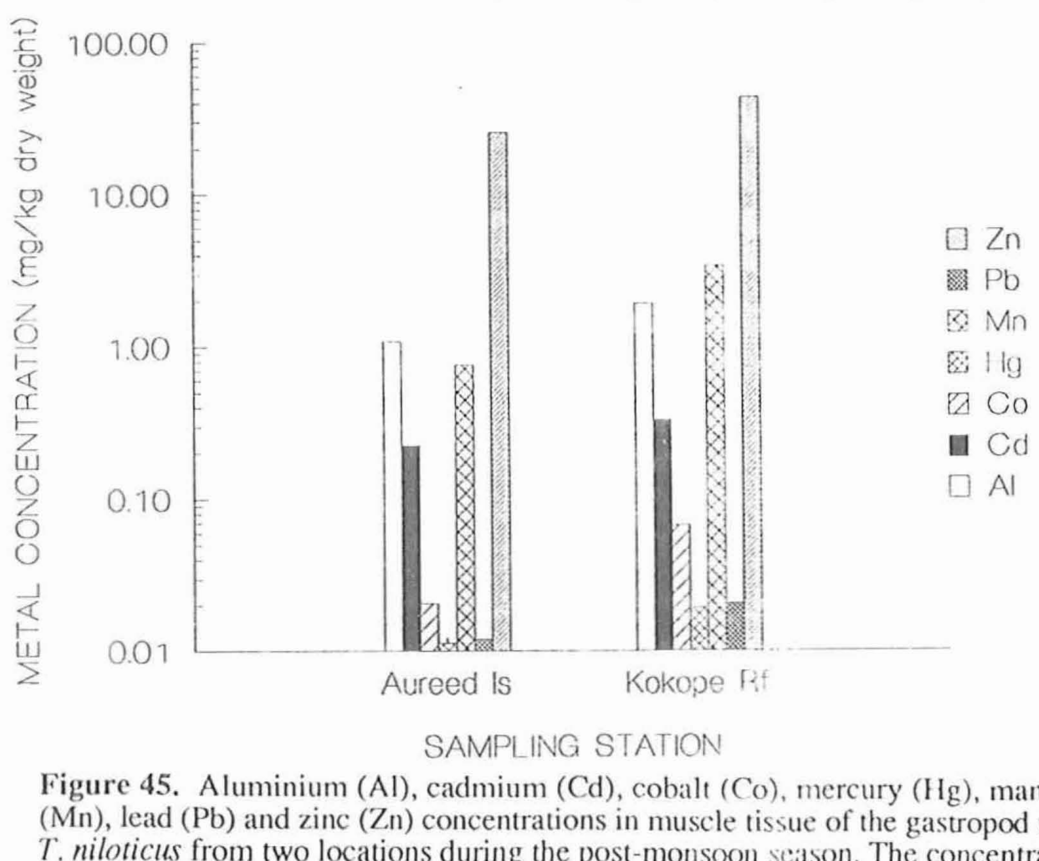

Figure 45. Aluminium (Al), cadmium (Cd), cobalt (Co), mercury (Hg), manganese (Mn), lead (Pb) and zinc (Zn) concentrations in muscle tissue of the gastropod mollusc *T. niloticus* from two locations during the post-monsoon season. The concentrations of all seven metals were significantly higher at Kokope Reef.

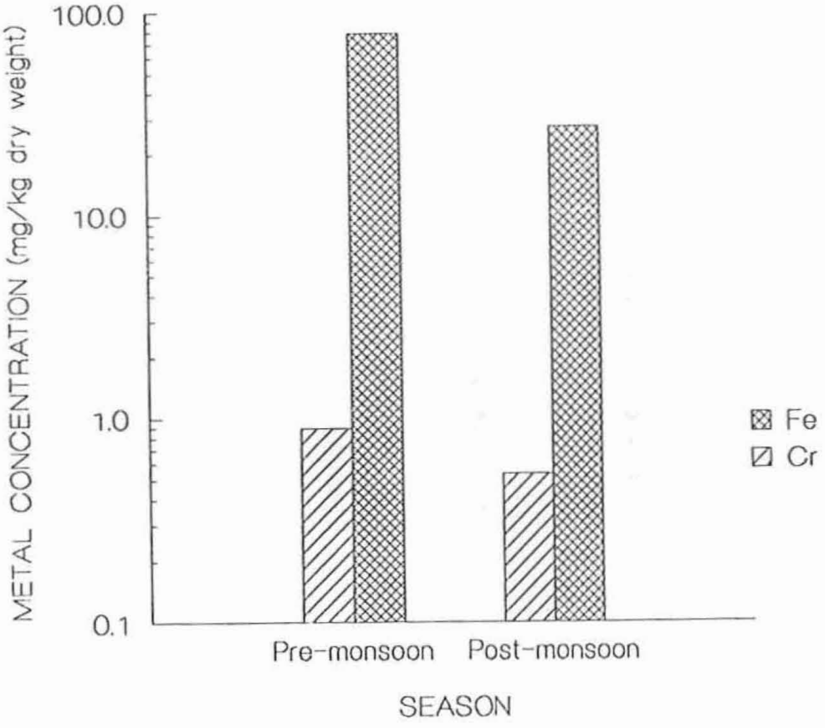

Figure 46. Chromium (Cr) and iron (Fe) concentrations in the muscle tissue of the gastropod mollusc *S. luhuanus* from Campbell Island during two seasons. The concentrations of both metals were significantly higher during the pre-monsoon period.

Stichopus chloronotus (sea cucumber)

Many combinations of metals displayed correlations which were significantly different from zero ($p<=0.05$) at individual locations within a season. Only iron and manganese concentrations were both strongly correlated and significantly different from zero across all locations and seasons.

Two-way Analysis of Variance based on transformed metal concentrations ($\log_e$(concentration+1)) in the body wall of *S. chloronotus* from two locations (Aureed Island and Kokope Reef) within two seasons (pre- and post-monsoon) is presented in Appendix Table 87. Five metals, cadmium (Cd), chromium (Cr), mercury (Hg), manganese (Mn) and nickel (Ni), displayed no statistically significant differences ($p>0.05$) among seasons or locations. Three metals, arsenic (As), copper (Cu) and iron (Fe), showed significant differences ($p<=0.05$) among seasons while five, aluminium (Al), copper (Cu), lead (Pb), selenium (Se) and zinc (Zn), displayed a significant difference among locations. Aluminium (Al), cobalt (Co), copper (Cu) and iron (Fe) concentrations displayed a statistically significant interaction between location and season ($p<=0.05$).

The concentrations (mg kg^{-1} dry weight) of 13 metals from all combinations of season and sampling station are presented in Appendix Table 88.

Seasonal patterns

Only arsenic (As) concentration was significantly higher across both locations. This was during the post-monsoon period (Appendix Table 88). Copper (Cu) concentration was elevated during the pre-monsoon season at Kokope Reef and during the post-monsoon period at Aureed Island, while iron (Fe) concentration was elevated during the post-monsoon period at Aureed Island only. These patterns are presented graphically in Figures 47 and 48 for Aureed Island and Kokope Reef respectively.

Spatial patterns

Lead (Pb), selenium (Se) and zinc (Zn) concentrations were significantly higher in samples from Kokope Reef than Aureed Island during both seasons (Appendix Table 88). Aluminium and copper concentrations were both significantly higher at Kokope Reef during the pre-monsoon season only. These patterns are presented graphically in Figures 49 and 50 for pre- and post-monsoon seasons respectively.

Regional variation

There are no other known studies that have measured trace metal concentrations in the body wall of *S. chloronotus*.

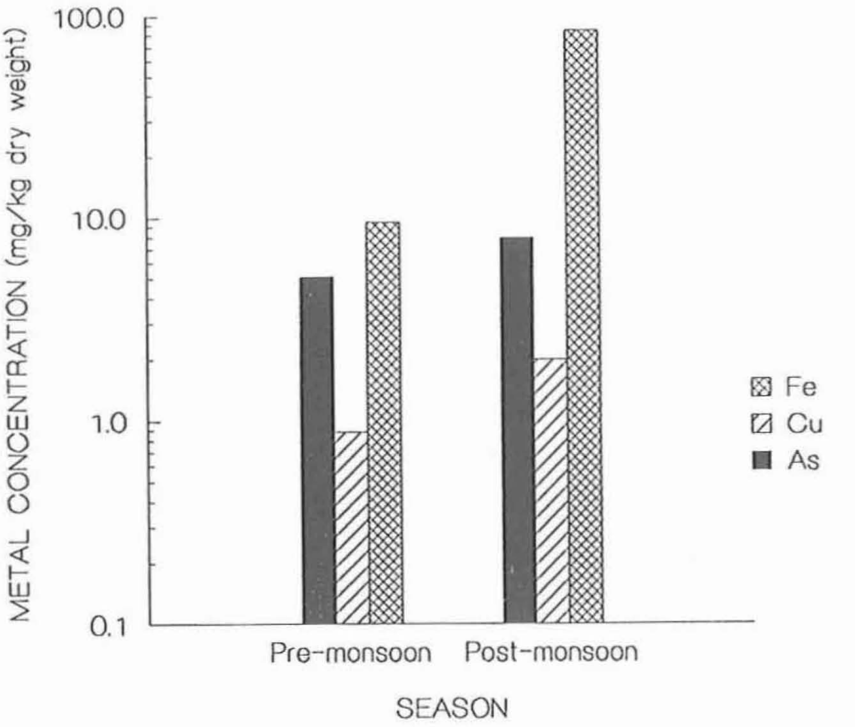

Figure 47. Arsenic (As), copper (Cu) and iron (Fe) concentrations in the body wall of the sea cucumber *S. chloronotus* from Aureed Island during two seasons. The concentrations of all three metals were significantly higher during the post-monsoon season.

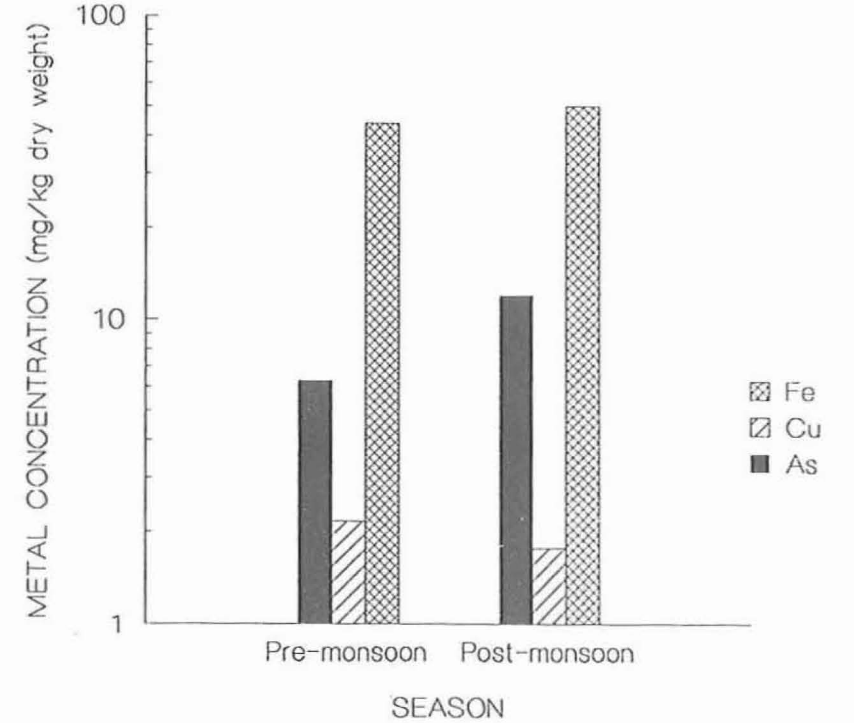

Figure 48. Arsenic (As), copper (Cu) and iron (Fe) concentrations in the body wall of the sea cucumber *S. chloronotus* from Kokope Reef during two seasons. Only the concentrations of arsenic and copper were significantly different among seasons. Arsenic concentration was higher during the post-monsoon period while copper concentration was higher during the pre-monsoon period.

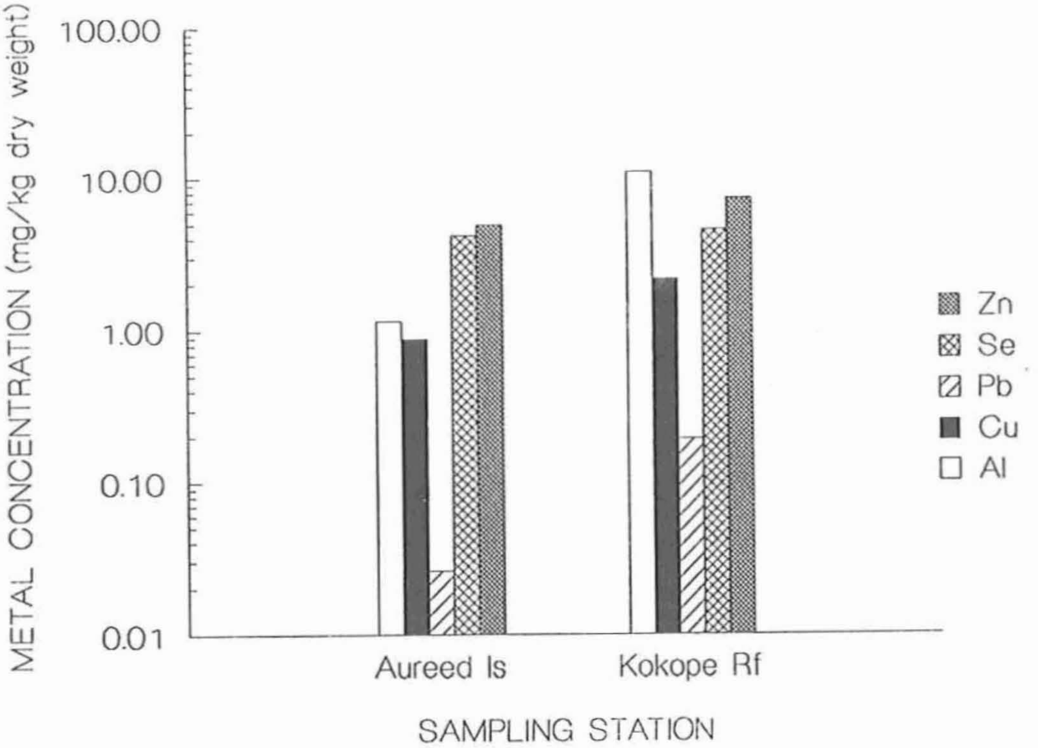

Figure 49. Aluminium (Al), copper (Cu), lead (Pb) selenium (Se) and zinc (Zn) concentrations in the body wall of the sea cucumber *S. chloronotus* from two locations during the pre-monsoon season. The concentrations of all five metals were significantly higher at Kokope Reef.

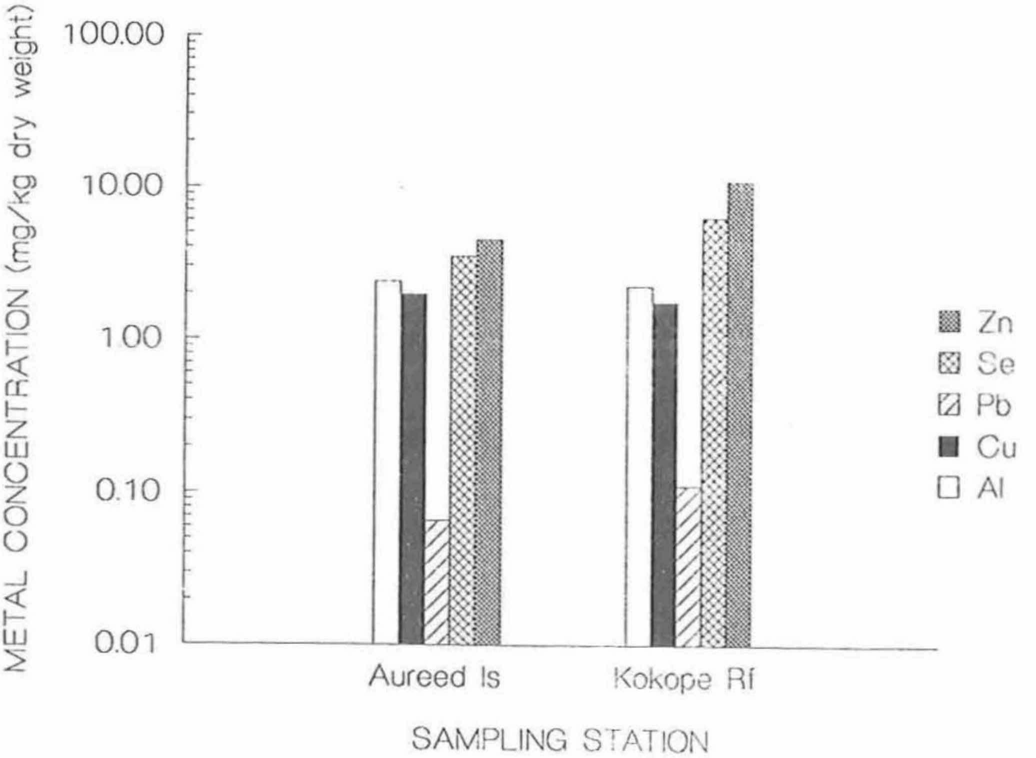

Figure 50. Aluminium (Al), copper (Cu), lead (Pb) selenium (Se) and zinc (Zn) concentrations in the body wall of the sea cucumber *S. chloronotus* from two locations during the post-monsoon season. Only the concentrations of lead, selenium and zinc were significantly different among locations.

Lutjanus carponotatus (stripey - reef fish)

Body length and liver weight were positively correlated and significantly different from zero ($p<=0.05$) at all combinations of location and season. There were no correlations between body length or liver tissue weight and metal concentrations which were significantly different from zero across all seasons and locations.

Many combinations of metals displayed correlations which were significantly different from zero at individual locations within a season. These correlations were rarely consistently significant across all locations and seasons. The following relationships between logarithmically transformed metal concentrations were both strongly correlated and significantly different from zero across both locations and seasons: cadmium and copper; and copper and zinc.

One-way Analysis of Variance based on transformed metal concentrations ($\log_e$(concentration+1)) in the liver of *L. carponotatus* from Aureed Island within two seasons (pre- and post-monsoon) is presented in Appendix Table 89. Seven metals, aluminium (Al), arsenic (As), cadmium (Cd), copper (Cu), iron (Fe), selenium (Se) and zinc (Zn), displayed no statistically significant differences ($p>0.05$) among the seasons. The remaining six metals, cobalt (Co), chromium (Cr), mercury (Hg), manganese (Mn), nickel (Ni) and lead (Pb), showed significant differences ($p<=0.05$) among seasons.

Analysis of Variance based on metal concentrations from two locations (Aureed Island and Kokope Reef) during the post-monsoon season is presented in Table Appendix 90. Six metals, aluminium (Al), arsenic (As), iron (Fe), mercury (Hg), manganese (Mn) and selenium (Se), displayed no statistically significant differences ($p>0.05$) among the two locations while the remaining six metals, cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), nickel (Ni), lead (Pb) and zinc (Zn), showed significant differences ($p<=0.05$) in concentrations.

Analysis of Variance based on metal concentrations in two different tissues (liver and muscle) from samples collected at Aureed Island during the post-monsoon season is presented in Appendix Table 91. Eleven metals, arsenic (As), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), manganese (Mn), nickel (Ni), lead (Pb), selenium (Se) and zinc (Zn), all except aluminium (Al) and mercury (Hg) displayed statistically significant differences ($p>0.05$) among the two tissues. Of the eleven metals that showed significant differences in concentration, all except nickel and lead were higher in the liver. Mercury concentrations were also markedly higher in the liver tissue, but the difference was not statistically significant ($p>0.05$).

The concentrations (mg kg^{-1} dry weight) of 13 metals from all combinations of season, sampling station and tissue are presented in Table Appendix 92.

Seasonal patterns

The concentrations of cobalt (Co), chromium (Cr), mercury (Hg) and manganese (Mn) in samples from Aureed Island were all highest during the pre-monsoon season (Appendix Table 92). This pattern is presented graphically in Figure 51. The statistically significant results for nickel and lead concentrations cannot be relied upon as the analytical detection limits for these two metals differed between seasons and many values were below the limits of detection. The relationship between body length and tissue weight at Aureed Island during the two seasons is presented in Figure 52. There is some evidence of a weight gain over the monsoon period which could account for the reduced concentrations of metals without an actual change in the total metal load within the tissue.

Spatial patterns

Cadmium (Cd), copper (Cu) and zinc (Zn) concentrations during the post-monsoon season were significantly higher in samples from Aureed Island, while chromium (Cr) was found in highest concentrations in samples from Kokope Reef (Appendix Table 92). These patterns are presented graphically in Figure 53. Once again, the statistically significant results for cobalt, nickel and lead cannot be relied upon as many values were below the limits of detection. It would nevertheless appear that cobalt and lead concentrations were higher at Aureed Island during the post-monsoon season.

Regional variation

The concentrations of six metals (Cd,Cu,Hg,Ni,Pb and Zn) within the liver of *L. carponotatus* from the present study are contrasted with the results of another published study (Burdon-Jones & Denton, 1984a) from the Great Barrier Reef in Table 8. Only metals for which published data were available are listed.

Table 8. Regional and seasonal variation in selected trace metal concentrations (mg kg^{-1} dry weight) within the liver of the reef fish *L. carponotatus*. Data are mean and range (in parentheses). n = sample size. * Mercury concentrations in mg kg^{-1} wet weight. Sources = [1] This study; [2] Burdon-Jones & Denton, 1984a. TS = Torres Strait. ndp = no data presented. bdl = below detection limit.

Location	Collection Date	n	Cadmium	Copper	Mercury*	Nickel	Lead	Zinc
Aureed Island [1] (TS, mid-shelf)	October,1991	15	51.2 (16.0-162)	42.7 (19.0-95.0)	0.41 (0.06-1.41)	0.13 (0.06-0.2)	0.17 (0.09-0.36)	160.7 (110-220)
	April,1992	15	41.9 (17.0-140)	47.8 (32.8-85.6)	0.13 (0.01-0.23)	bdl <0.5	0.76 (<0.4-2.9)	152.0 (120-209)
Kokope Reef [1] (TS, nearshore)	April,1992	15	13.62 (4.0-27.8)	36.1 (19.2-54.3)	0.17 (0.04-0.48)	0.57 (<0.5-1.5)	<0.4 bdl	112.1 (82-155)
Eagle Island [2] (GBR, mid-shelf)	February, 1981	1	19.1	27.8	0.14	<0.43	<0.97	148
Orpheus Island [2] (GBR, nearshore)	December, 1980 (132-193)	4	19.2 (4.8-29.5)	55.0 (31.5-83.7)	0.51 (0.12-1.03)	ndp (<0.38-<1.24)	ndp	169 (<0.91-1.36)
Heron Island [2] (GBR, offshore)	January,1981 (123-152)	3	23.05 (12.0-29.7)	33.9 (22.2-46.7)	0.15 (0.09-0.26)	ndp (<0.36-<0.43)	ndp	140 (<0.83-<0.99)

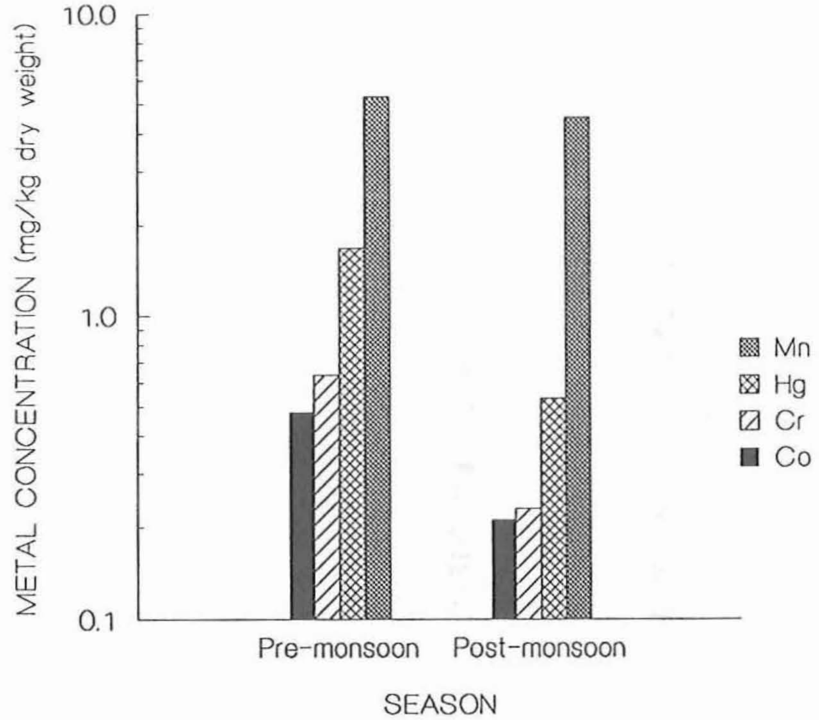

Figure 51. Cobalt (Co), chromium (Cr), mercury (Hg) and manganese (Mn) concentrations in the liver of the reef fish *L. carponotatus* from Aureed Island during two seasons. The concentrations of all four metals were significantly higher during the pre-monsoon period.

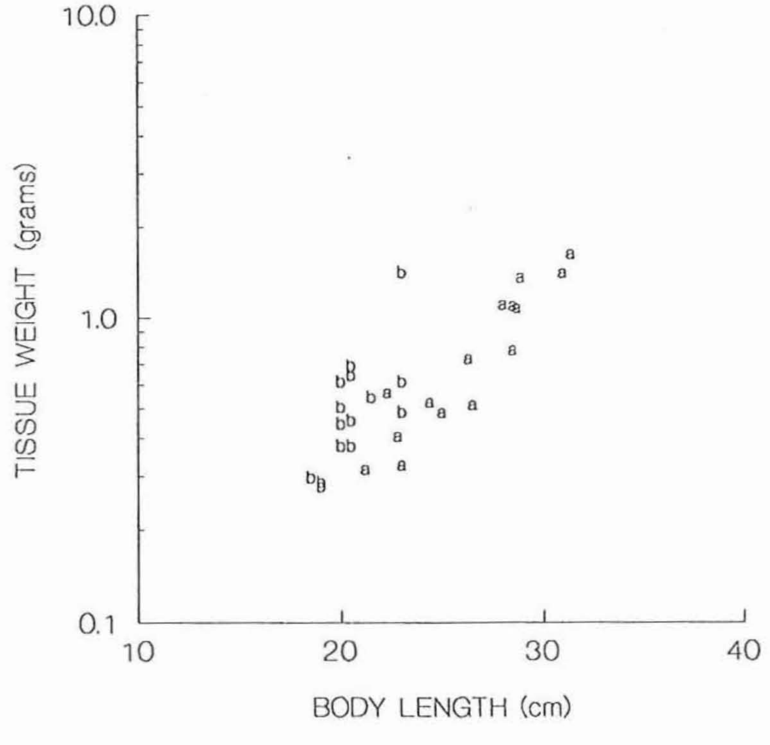

Figure 52. Relationship between body length and liver tissue dry weight in the reef fish *L. carponotatus* from Aureed Island. Samples are from the pre-monsoon (a) and post-monsoon (b) periods

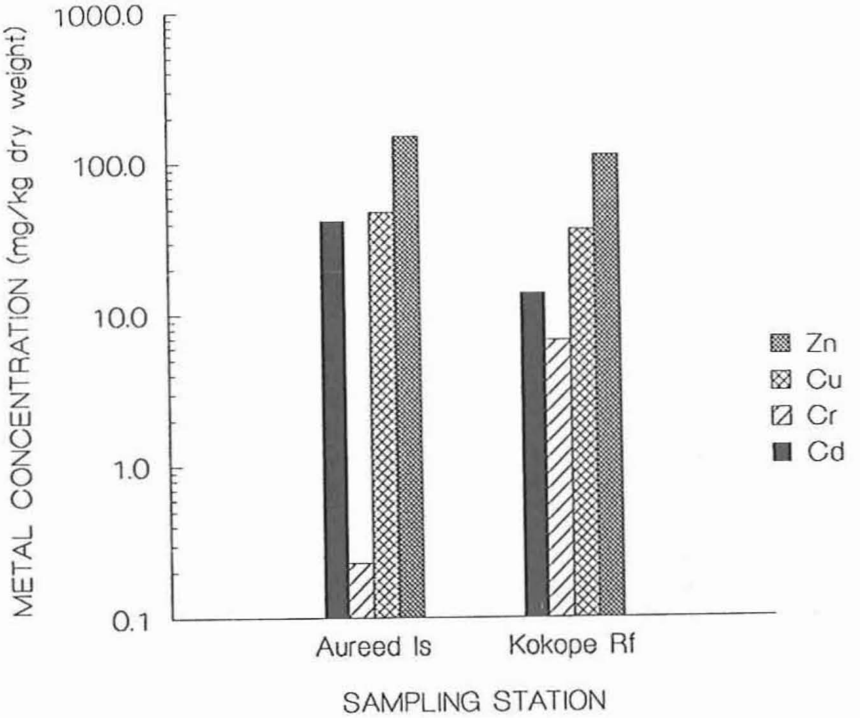

Figure 53. Cadmium (Cd), chromium (Cr), copper (Cu) and zinc (Zn) concentrations in the liver of the reef fish *L. carponotatus* from two locations during the post-monsoon season. The concentrations of all four metals were significantly different among locations. Only chromium concentration was higher at Kokope Reef.

Results show that the concentrations of copper, mercury, nickel, lead and zinc in samples from Aureed Island and Kokope Reef (this study) fall within the range of values that has been reported for similarly located (nearshore or mid-shelf) reefs within the GBR. Only the concentration of cadmium in samples from Aureed Island are elevated when compared to GBR locations.

Polymesoda erosa (mangrove cockle)

Shell length and tissue weight were positively correlated and significantly different from zero ($P<=0.05$) at all stations during both sampling periods except for Saibai Island (which was negatively correlated and not significant) and Shelburne bay (which was positively correlated but not significant) during the pre-monsoon period. The $\log_e$ of dry tissue weight consistently provided the strongest and most significant correlations.

There were no consistent correlations between shell length or tissue weight and metal concentrations. Once again, many combinations of metals displayed correlations which were significantly different from zero ($p<=0.05$) at individual locations within a season, but none was consistently significant among all locations and seasons. The only correlation between logarithmically transformed metal concentrations which was consistent, but not significantly different from zero among all locations and seasons, was between iron and manganese.

Two-way Analysis of Variance based on transformed metal concentrations ($\log_e$(concentration+1)) in the whole soft tissue of *P. erosa* from Boigu and Saibai Islands during the two sampling periods (seasons) are presented in Appendix Table 93. Only two metals, copper (Cu) and mercury (Hg), displayed statistically significant differences ($p<=0.05$) among seasons while four, aluminium (Al), cadmium (Cd), copper (Cu) and manganese (Mn), showed significant differences ($p<=0.05$) among the two locations.

One-way Analysis of Variance based on transformed metal concentrations ($\log_e$(concentration+1)) in the whole soft tissue of *P. erosa* from Boigu and Saibai Islands, Saibai Village and Shelburne Bay during the pre-monsoon season and from Boigu, Saibai and Parama Islands, and two stations on the Papua New Guinea mainland (Aberemuba Village and West Aberemuba) during the post-monsoon season are presented in Appendix Tables 94 and 95 respectively. Ten metals, aluminium (Al), arsenic (As), cadmium (Cd), cobalt (Co), copper (Cu), iron (Fe), mercury (Hg), manganese (Mn), nickel (Ni) and selenium (Se), displayed significant differences ($p<=0.05$) among locations during the pre-monsoon period (Appendix Table 94) while a different combination of ten, aluminium (Al), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), manganese (Mn), nickel (Ni), lead (Pb) and selenium (Se), displayed significant differences ($p<=0.05$) among locations during the post-monsoon period (Appendix Table 95). Note that only two of the seven locations that were sampled are common to the two periods.

The concentrations (mg kg^{-1} dry weight) of all metals analysed from the seven sampling stations within two seasons are presented in Appendix Tables 96 to 108.

Seasonal patterns

Concentrations of the two metals (Cu and Hg) which were significantly different among seasons are presented graphically in Figure 54 for Saibai Island, although both Boigu and Saibai Islands display the same pattern. The concentrations of both metals were higher during the post-monsoon sampling period (see Appendix Tables 101 and 103). The concentrations of aluminium (Al), arsenic (As), cadmium (Cd), nickel (Ni) and selenium (Se) also varied substantially between seasons, but the differences were not statistically significant. All displayed increases over the monsoon period. The relationship between shell length and tissue weight among seasons is presented in Figures 55 and 56 for Boigu and Saibai Islands respectively. The different relationship between shell length and tissue weight among seasons in samples from Saibai Island, and differences in shell size of samples from Saibai Island make interpretation of seasonal differences in trace metal concentration more difficult to interpret with confidence. However, there is nothing in the data to suggest that seasonal differences in metal concentrations are attributable to changes in tissue weight. Further work is in progress in an attempt to establish a better measure of age/size of individuals by weighing the shells.

Spatial patterns

Of the ten metals that displayed significant differences among locations during the pre-monsoon sampling period, four (Cd,Fe,Hg and Mn) had highest concentrations in samples from stations along the PNG coast (Boigu or Saibai Islands or Saibai Village) while six (Al,As,Co,Cu,Ni and Se) had highest concentrations in samples from Shelburne Bay. These two patterns are presented graphically in Figures 57 and 58 respectively.

Cadmium (Cd) concentrations in samples from Saibai Village were significantly higher than those from the other three locations. While the concentrations of cadmium in samples from Boigu and Saibai Islands were also significantly different (Saibai Island being higher), samples from neither location had significantly higher concentrations of cadmium than those from Shelburne Bay. However, the concentrations of iron (Fe), mercury (Hg) and manganese (Mn) in samples from Shelburne Bay were all significantly lower than those from both Boigu and Saibai Islands.

Only the concentrations of arsenic (As) and nickel (Ni) were significantly higher in samples from Shelburne Bay when compared to both Boigu and Saibai Islands. The concentrations of aluminium (Al), cobalt (Co), copper (Cu) and selenium (Se) in samples from Shelburne Bay were significantly higher than either Boigu or Saibai Islands, but not both. Aluminium and selenium were found in significantly higher concentrations in samples from Boigu Island when compared to Saibai Island, while arsenic, cadmium and manganese were higher in samples from Saibai Island. There were no significant differences in the concentrations of the other eight metals between the two locations during the pre-monsoon period.

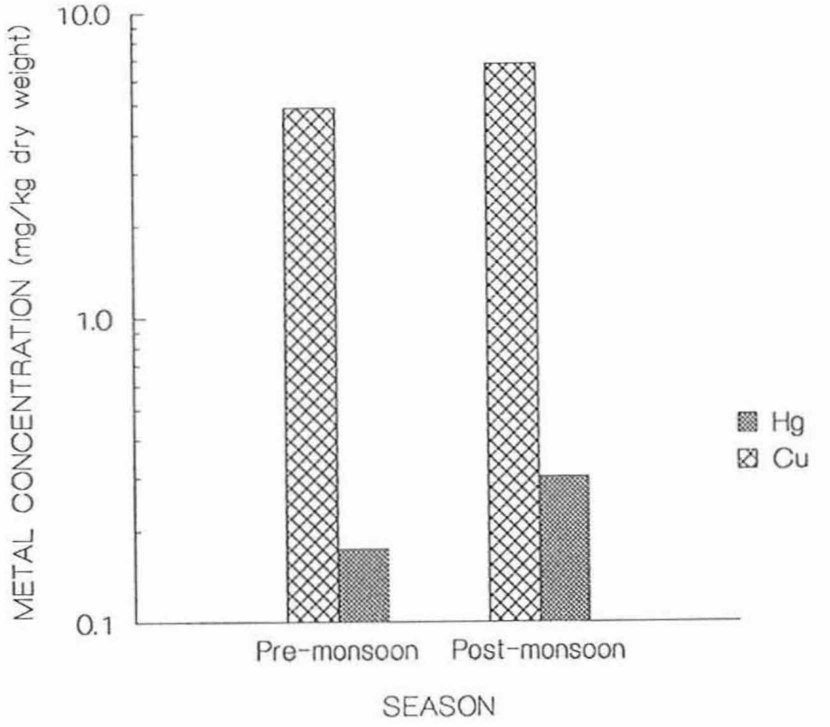

Figure 54. Copper (Cu) and mercury (Hg) concentrations in the soft tissue of the cockle *P. erosa* from Saibai Island during two seasons. The concentrations of both metals were significantly higher during the post-monsoon season.

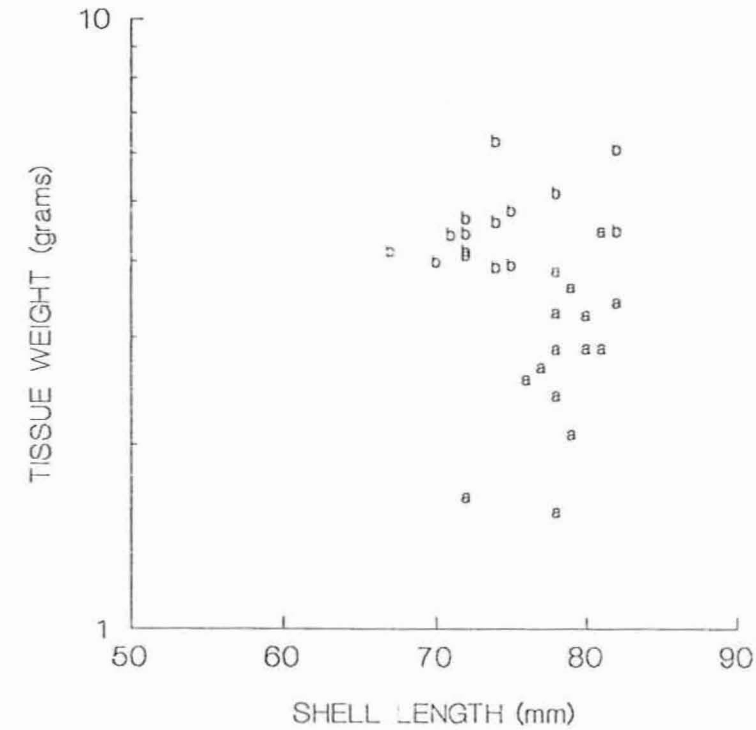

Figure 55. Relationship between shell length and soft tissue dry weight in the cockle *P. erosa* from Boigu Island. Samples are from the pre-monsoon (a) and post-monsoon (b) periods.

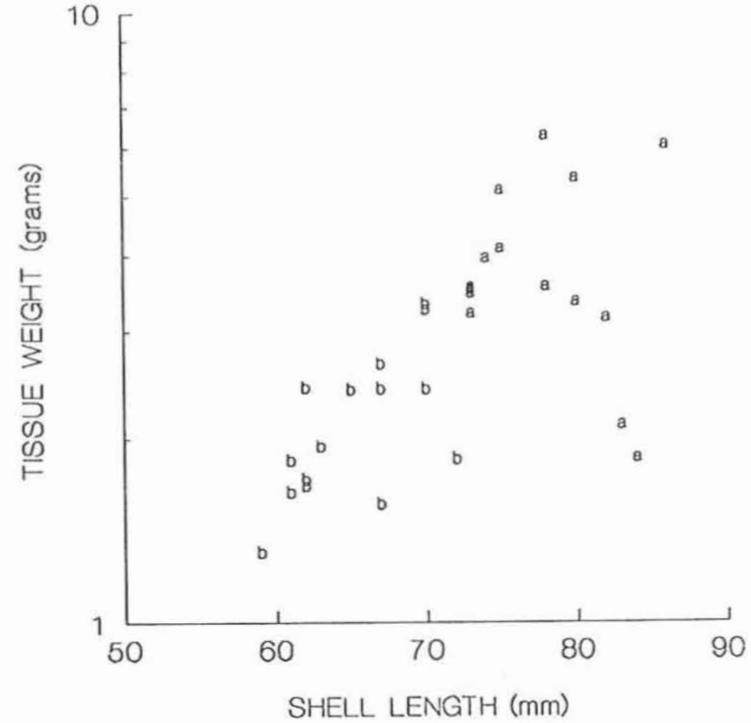

Figure 56. Relationship between shell length and soft tissue dry weight in the cockle *P. erosa* from Saibai Island. Samples are from the pre-monsoon (a) and post-monsoon (b) periods.

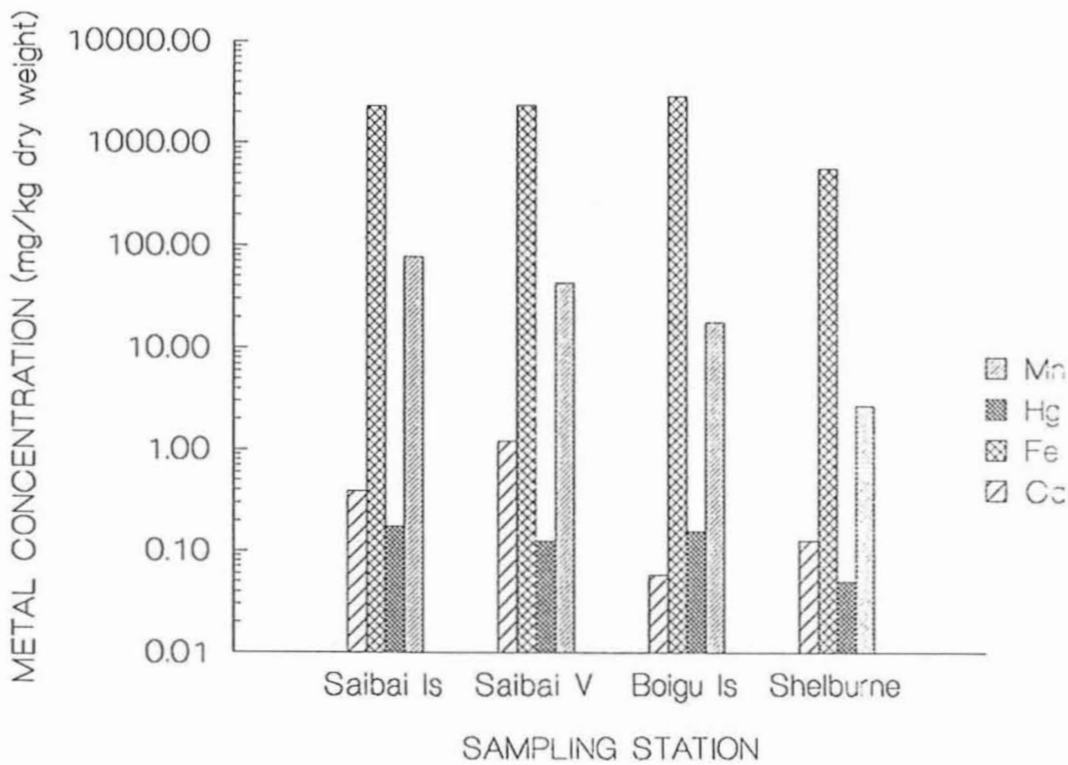

Figure 57. Cadmium (Cd), iron (Fe), mercury (Hg) and manganese (Mn) concentrations in the soft tissue of the cockle *P. erosa* from four locations during the pre-monsoon season. The concentrations of the metals illustrated were generally higher at coastal island locations (Boigu Island, Saibai Island or Saibai Village) than Shelburne Bay.

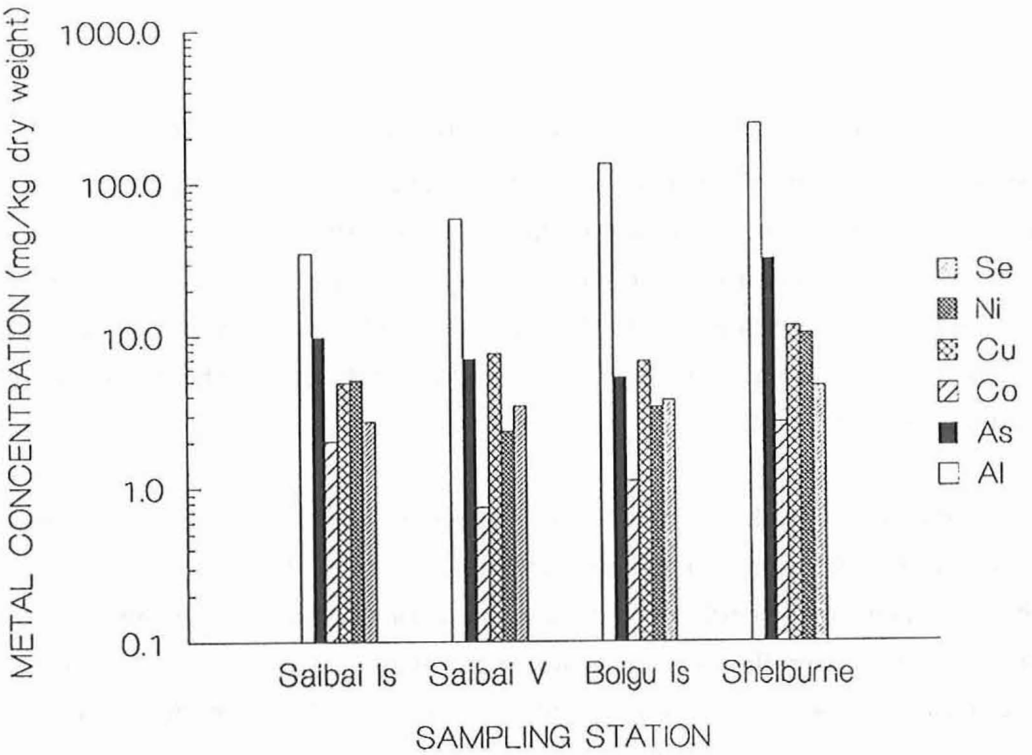

Figure 58. Aluminium (Al), arsenic (As), cobalt (Co), copper (Cu), nickel (Ni) and selenium (Se) concentrations in the soft tissue of the cockle *P. erosa* from four locations during the pre-monsoon season. The concentrations of all metals illustrated were significantly higher at Shelburne Bay than the coastal island locations (Boigu Island, Saibai Island or Saibai Village).

Of the ten metals that displayed significant differences among locations during the post-monsoon sampling period, eight (Al,Co,Cr,Cu,Fe,Mn,Ni and Pb) had highest concentrations in samples from stations on the PNG mainland (Aberemuba Village and West Aberemuba) while only two (Cd and Se) had highest concentrations in samples from the coastal islands (Boigu, Saibai or Parama). These two patterns are presented graphically in Figures 59 and 60 respectively. The eight metals in Figure 59 have been separated into two groups of four (Figs. 59a and b), primarily for clarity of presentation (but see below).

Concentrations of aluminium (Al), cobalt (Co), chromium (Cr) and lead (Pb) in samples from West Aberemuba were significantly higher than in samples from Aberemuba Village and the coastal islands (Fig. 59a). Concentrations of copper (Cu), iron (Fe) and nickel (Ni) from West Aberemuba were higher but not significantly different from those of Aberemuba Village, but they were significantly higher than one or more of the coastal islands (Fig. 59b). Only manganese (Mn) displayed significantly higher concentrations in samples from Aberemuba Village when compared with those of West Aberemuba, which were in turn significantly higher than Boigu Island but not Saibai Island.

Considering only the coastal islands (Boigu, Saibai and Parama - Fig. 59), there were no significant differences among locations in the concentrations of aluminium, cobalt, chromium, copper and nickel. However, there were significant differences between the three locations for iron, manganese and lead. Manganese and lead concentrations were significantly higher in samples from Parama Island, followed by Saibai for manganese and Boigu for lead, while iron concentrations were significantly higher in samples from Boigu followed by Saibai.

The concentration of cadmium was highest in samples from Saibai Island, significantly higher than from Boigu Island, but not significantly different from all other locations (Fig. 60; Appendix Table 98). In contrast, highest concentrations of selenium were found in samples from Boigu Island. These were significantly higher than from Saibai Island and West Aberemuba, but not significantly different from Parama Island and Aberemuba village (Fig. 60; Appendix Table 107).

Regional variation

There are no other known studies that have measured trace metal concentrations in the soft tissue of *P. erosa*.

Summary

Six species that were collected as potential indicator organisms displayed statistically significant differences in the concentrations of many trace metals between seasons and among locations. These were the bivalve molluscs *T. crocea*, *T. maxima*, *P. margaritifera* and *P. erosa*, the gastropod mollusc *T. niloticus*, and the reef fish *L. carponotatus*. These six species are identified as good indicator organisms on the basis that they do not appear to regulate the concentrations of trace metals in their tissues, but rather, to accumulate them to concentrations well above those in the environment. The variation in trace metal concentration reflects differences in bio-availability.

A further three species, the seagrasses *T. hemprichii* and *T. ciliatum* (collected during one season only) and the sea cucumber *S. chloronatus*, showed significant differences in the concentrations of many trace metals among locations. The remaining three species, the bivalve molluscs *H. hyotis* and *C. plinthota*, and the gastropod mollusc

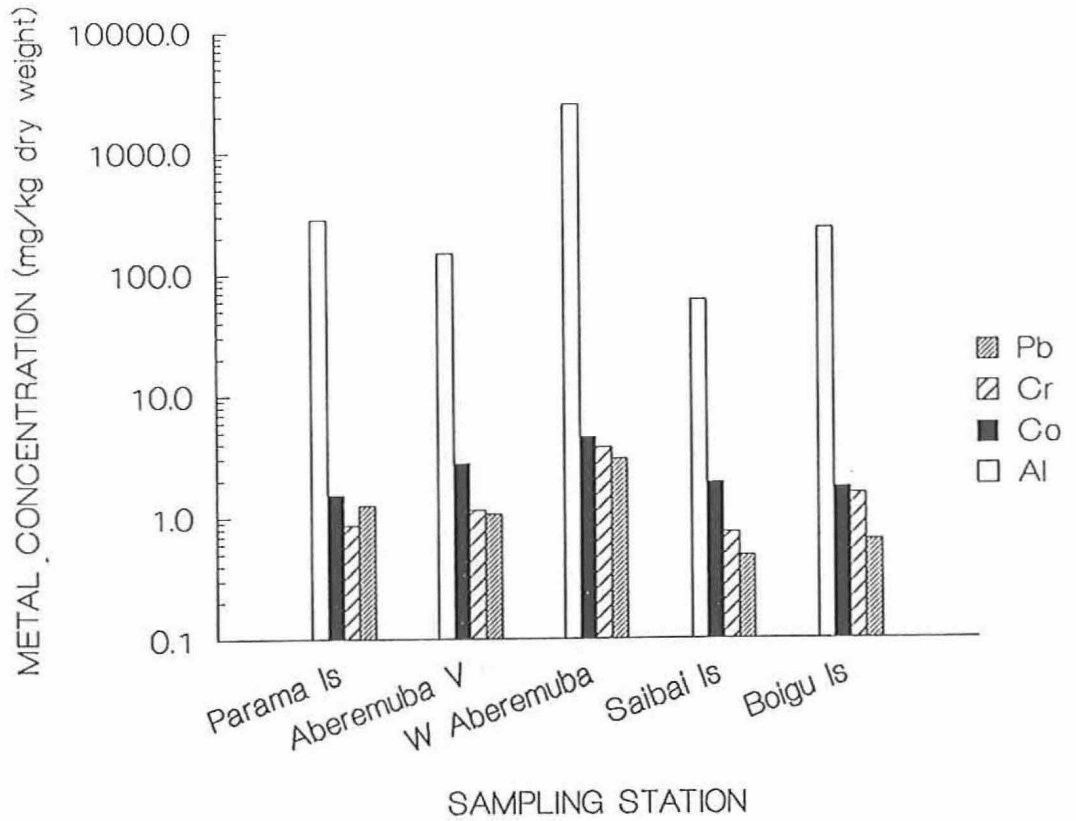

Figure 59a. Aluminium (Al), cobalt (Co), chromium (Cr) and lead (Pb) concentrations in the soft tissue of the cockle *P. erosa* from five locations during the post-monsoon season. The concentrations of all metals illustrated were significantly higher at West Aberemuba than Aberemuba Village and the coastal island locations (Boigu, Saibai and Parama Islands).

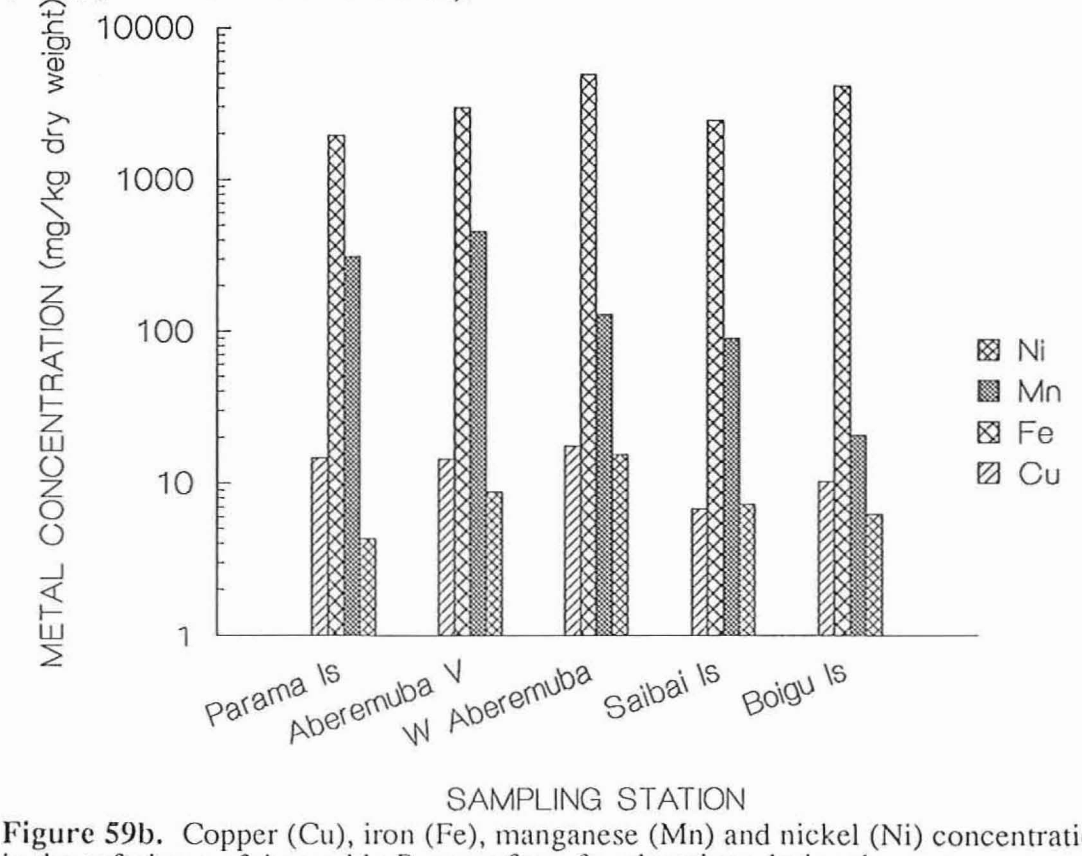

Figure 59b. Copper (Cu), iron (Fe), manganese (Mn) and nickel (Ni) concentrations in the soft tissue of the cockle *P. erosa* from four locations during the post-monsoon season. The concentrations of all metals illustrated were significantly higher at one or both of the mainland locations (West Aberemuba and Aberemuba Village) than one or more of the coastal island locations (Boigu, Saibai and Parama Islands).

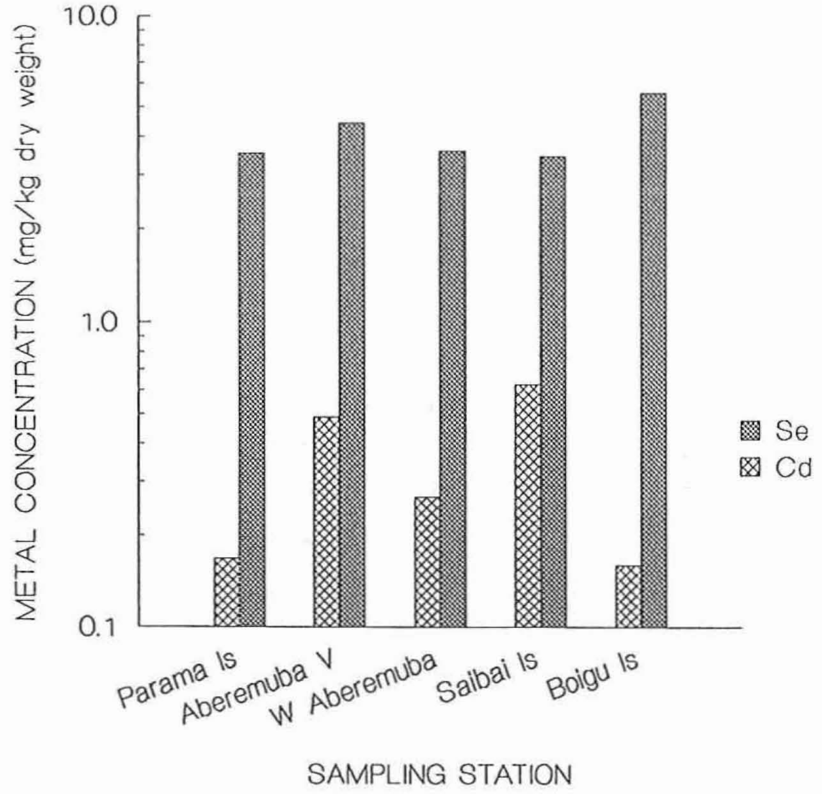

Figure 60. Cadmium and selenium (Se) concentrations in the soft tissue of the cockle *P. erosa* from five locations during the post-monsoon season. The concentrations of both metals were significantly higher at one of the coastal island locations (Boigu, Saibai and Parama Islands) than West Aberemuba or Aberemuba Village on the Papua New Guinea mainland.

S.luhuanus, displayed relatively few significant differences in trace metal concentrations. On this basis, these three species are thought to be partial regulators of trace metal concentrations in the selected tissues and/or display such high levels of variation among individuals that differences in metal concentrations are difficult to detect without increasing the sample size greatly.

Seasonal patterns in trace metal bio-availability fall into two groups based loosely around location: central and northern Torres Strait. In the central Torres Strait, focused on Aureed Island, most trace metals either displayed little seasonal variation or else were elevated during the pre-monsoon period (e.g. *T. crocea*, *T. maxima*, *P. margaritifera*, *L. carponotatus*). In the northern Torres Strait, focused on Kokope Reef, Campbell Island and the coastal islands of Boigu and Saibai, many trace metals displayed elevated concentrations during the post-monsoon season (e.g. *T. crocea*, *T. maxima*, *P. erosa*). The identity of the trace metals which displayed this variation differed to some extent between species.

Spatial patterns in trace metal bio-availability appear to be more species, metal and season dependant. During the post-monsoon period, many metals displayed highest concentrations at the northern most locations, particularly Kokope Reef (e.g. *T. hemprichii*, *T. crocea*, *T. maxima*, *P. margaritifera*, *T. niloticus*). However, this pattern was reversed for some metals (particularly chromium and nickel) and not so clear for *L. carponotatus*. There were generally fewer significant differences in trace metal concentrations among locations during the pre-monsoon period (e.g. *T. crocea*, *P. margaritifera*, *T. niloticus*).

Regional variation in cadmium, copper, mercury, nickel, lead and zinc concentrations was examined within various tissues of *T. crocea*, *T. maxima*, *P. margaritifera*, *H. hyotis* and *L. carponotatus*. Only cadmium concentrations were found to be elevated throughout the Torres Strait when compared to Great Barrier Reef waters. However, there is also an indication that copper concentrations might also be slightly elevated when compared to some locations within the Great Barrier Reef.

Sampling Design

Power estimates for specified concentration changes, based on the pilot study data, are presented for sediments, *T. crocea*, *T. maxima* and *P. erosa* in Tables 9 to 12 respectively. They are presented in order to assist in the refinement of a sampling strategy for the main study. Ultimately, measures of natural variability among 'impacted' and 'control' locations will be derived from the main study and provide the basis for calculating the power to detect concentration changes over time in any future monitoring programme.

The changes that might be detected have been expressed as an increase in the range for each trace metal (across the stations from which it has been sampled) above that found during the pilot study. An increase in the range *R* will occur if the concentration of a metal at one location increases relative to the other sampling stations. This could occur at the sampling location closest to the hypothesized source of impact. Two scenarios are provided for sediments, four and six sampling stations per transect. These correspond to off-shore transects into the central Torres Strait and the long-shore transect parallel to the coast respectively. Options for numbers of sites have been included for *T. crocea* and *T. maxima* to assess sensitivity and because of uncertainties with respect to the level of funding for analyses.

Power estimates and concentration changes within sediments (Table 9) show that with the existing sampling regime (3 sites per station) there is good power (>0.76) to detect relatively small changes in copper and zinc concentrations. These two metals have been identified as important trace metals which are associated with Fly River discharge. Only relatively large changes in arsenic, cadmium and, in particular, mercury and selenium are detectable with the present sampling regime. However, these trace metals are not presently believed to be major constituents of Fly River discharge.

Power estimates and concentration changes within the kidney of *T. crocea* and *T. maxima* (Tables 10 and 11), which vary with the number of sites per station (reef) (Tables a and b), illustrate that the ability to detect concentration changes over time (increase in R) while maintaining a reasonable level of power (=>0.8) is sensitive to the number of sites sampled. The concentration change that one can reasonably expect to detect is seen to vary markedly between metals. Relatively smaller changes in the concentration of cadmium, copper and zinc can be detected, for a given number of sites sampled, than arsenic, mercury and selenium. This is true for *T. crocea*, *T. maxima* and *P. erosa*.

Table 9. Power estimates corresponding to concentration changes (increase in *R*) for selected metals in sediments sampled along transects with four (**a**) and six (**b**) stations per transect. These correspond to off-shore and long-shore transects respectively. An increase in *R* corresponds to an hypothesized change in the range of mean concentrations above that detected during the pilot study.

a.

Metal	Number of sampling stations	Number of sites	Increase in *R*	Power
As	4	3	150%	>0.76
Cd	4	3	75%	>0.76
Cu	4	3	10%	>0.76
Hg	4	3	750%	>0.76
Se	4	3	500%	>0.76
Zn	4	3	10%	>0.76

b.

Metal	Number of sampling stations	Number of sites	Increase in *R*	Power
As	6	3	700%	0.83
Cd	6	3	350%	0.85
Cu	6	3	10%	>0.88
Hg	6	3	550%	0.80
Se	6	3	600%	0.83
Zn	6	3	10%	>0.88

Table 10. Power estimates corresponding to concentration changes (increase in *R*) for selected metals within the kidney of *T. crocea* sampled along transects of four stations with four (**a**) and eight (**b**) sites per station. An increase in *R* corresponds to an hypothesized change in the range of mean concentrations above that detected during the pilot study.

a.

Metal	Number of sampling stations	Number of sites	Increase in *R*	Power
As	4	4	600%	0.91
Cd	4	4	150%	>0.92
Cu	4	4	225%	>0.92
Hg	4	4	325%	>0.92
Se	4	4	1250%	>0.92
Zn	4	4	25%	>0.92

b.

Metal	Number of sampling stations	Number of sites	Increase in *R*	Power
As	4	8	300%	0.80
Cd	4	8	25%	0.82
Cu	4	8	75%	0.82
Hg	4	8	150%	0.90
Se	4	8	700%	0.90
Zn	4	8	25%	>0.99

Table 11. Power estimates corresponding to concentration changes (increase in *R*) for selected metals within the kidney of *T. maxima* sampled along transects of four stations with four (**a**) and eight (**b**) sites per station. An increase in *R* corresponds to an hypothesized change in the range of mean concentrations above that detected during the pilot study.

a.

Metal	Number of sampling stations	Number of sites	Increase in *R*	Power
As	4	4	250%	0.87
Cd	4	4	150%	0.87
Cu	4	4	10%	>0.92
Hg	4	4	320%	0.83
Se	4	4	200%	0.85
Zn	4	4	20%	>0.87

b.

Metal	Number of sampling stations	Number of sites	Increase in *R*	Power
As	4	8	150%	0.92
Cd	4	8	75%	0.92
Cu	4	8	10%	>0.99
Hg	4	8	200%	0.90
Se	4	8	100%	0.86
Zn	4	8	10%	>0.98

Table 12. Power estimates corresponding to concentration changes (increase in *R*) for selected metals within the whole soft tissue of *P. erosa* sampled along transects of three stations with three sites per station. An increase in *R* corresponds to an hypothesized change in the range of mean concentrations above that detected during the pilot study.

Metal	Number of sampling stations	Number of sites	Increase in *R*	Power
As	3	3	150%	>0.69
Cd	3	3	50	>0.69
Cu	3	3	25%	>0.69
Hg	3	3	150%	>0.69
Se	3	3	250%	>0.69
Zn	3	3	75%	>0.69

Community Fishery

The muscle tissue concentrations (mg kg^{-1} wet weight) of selected metals in seventeen species of fish from the Torres Strait are presented in Table 13. Note that samples of *Harengula ovalis* and the sardine/hardyhead represent whole body concentrations. Only those metals for which there are NHMRC maximum permitted concentrations (MPCs)

Table 13. Metal concentrations (mean and range (in parentheses) in mg kg^{-1} wet weight) in the muscle tissue of seventeen species of fish from the Torres Strait. n = sample size. * maximum permitted concentration is based on inorganic arsenic only, while concentrations represent total arsenic. ** the mean concentration based on a prescribed number of sampling units. bdl = below detection limits. [1] prepared from whole body.

Species	Location	n	Antimony	Arsenic	Cadmium	Copper	Mercury	Lead	Selenium	Zinc
NMHRC Maximum permitted concentration:			1.5	1.0*	0.2	10.0	0.5**	1.5	1.0	150.0
A. barracuda	Coconut Is	1	0.02	3.80	bdl	0.65	0.45	0.06	0.67	11.0
C. fulvogutus	Murray Is	1	0.04	1.20	bdl	0.46	0.05	0.07	0.47	10.0
C. schoenleinii	Coconut Is	1	bdl	3.40	bdl	0.12	0.01	0.02	0.26	6.8
E. fasciatus	Murray Is	1	0.05	3.70	0.01	0.20	0.04	0.05	0.28	2.8
E. quoyanus	Stephen Is	1	bdl	0.83	bdl	0.10	0.02	0.01	0.18	3.5
H. ovalis[1]	Murray Is	3	bdl	7.13	0.29	1.20	0.04	0.13	1.07	26.0
				(5.90-9.40)	(0.26-0.34)	(1.00-1.40)		(0.03-0.04)	(0.06-0.18)	(0.51-1.40)
	(18.0-34.0)									
Sardine / hardyhead[1]	Darnley Is	2	bdl	2.60	0.20	0.66	0.02	0.07	0.45	22.0
				(2.30-2.90)	(0.08-0.31)	(0.48-0.84)		(0.02-0.02)	(0.04-0.09)	(0.42-0.47)
	(21.0-23.0)									
Sardine / hardyhead[1]	Murray Is	3	bdl	4.83	0.22	0.59	0.03	0.05	0.57	23.3
				(4.60-5.30)	(0.13-0.35)	(0.41-0.75)		(0.03-0.03)	(0.03-0.07)	(0.46-0.64)
	(19.0-29.0)									
L. calcarifer	Boigu Is	1	bdl	3.50	0.01	0.25	0.08	0.04	0.54	4.3
L. fletus	Mabuiag Is	1	0.01	2.50	0.01	0.30	0.04	0.04	0.25	7.7
L. carponotatus	Stephen Is	1	bdl	7.10	bdl	0.23	0.12	0.02	0.37	5.7
	Warraber Is	1	bdl	4.00	bdl	0.30	0.05	0.02	0.29	4.5
	Yam Is	1	bdl	1.00	bdl	0.20	0.07	0.03	0.32	10.0
P. leopardus	Coconut Is	1	bdl	0.55	bdl	0.13	0.04	0.03	0.56	2.9
P. maculatus	Stephen Is	1	bdl	0.30	bdl	0.16	0.02	0.01	0.23	3.9
P. flavomaculatus	Warraber Is	3	bdl	3.07	bdl	0.34	0.06	0.04	0.25	6.3
				(1.90-4.10)		(0.27-0.47)		(0.05-0.07)	(0.03-0.06)	(0.20-0.28)
	(6.1-6.6)									
	Yorke Is	1	bdl	2.4	bdl	0.33	0.03	0.01	0.23	8.3
P. pictus	Warraber Is	1	bdl	3.50	bdl	0.15	0.03	0.02	0.20	6.5
P. waigiensis	Mabuiag Is	1	bdl	0.66	0.01	0.39	0.06	0.04	0.29	5.7
S. commerson	Coconut Is	1	0.01	1.90	bdl	0.18	0.08	0.06	0.52	9.8
	Yorke Is	1	0.01	2.40	bdl	0.21	0.06	0.03	0.70	13.0

(Table 13 cont.)

Species	Location	n	Antimony	Arsenic	Cadmium	Copper	Mercury	Lead	Selenium	Zinc
S. guttatus	Coconut Is	5	0.01	0.93	0.01	0.17	0.01	0.03	0.11	2.5
			(bdl-0.10)	(0.79-1.20)	(bdl-0.01)	(0.13-0.23)		(bdl-0.02)	(0.02-0.04)	(0.06-0.17)
	(1.5-4.0)									
	Darnley Is	2	0.02	0.88	0.01	0.44	0.02	0.05	0.41	7.8
			(0.02-0.02)	(0.46-1.30)	(bdl-0.01)	(0.43-0.45)		(0.01-0.03)	(0.04-0.05)	(0.37-0.44)
	(7.0-8.6)									
	Warraber Is	3	0.01	0.38	bdl	0.19	bdl	0.02	0.10	2.0
			(bdl-0.04)	(0.33-0.43)		(0.15-0.22)			(0.02-0.03)	(0.08-0.12)
	(1.7-2.5)									
	Yam Is	2	0.02	0.34	0.02	0.33	bdl	0.01	0.04	2.7
			(0.02-0.02)	(0.25-0.43)	(0.02-0.02)	(0.14-0.52)			(bdl-0.02)	(0.02-0.05)
	(1.6-3.8)									
S. spinus	Mabuiag Is	1	bdl	0.46	bdl	0.47	bdl	0.05	0.14	10.0

are presented. Note also that the MPC for arsenic in fish, molluscs and crustaceans is based on the inorganic portion, while the concentrations presented represent total arsenic. Most of the arsenic is in the organic form (NHMRC, 1991) and may represent 90-95% of total arsenic (H. Mawhinney, pers. comm.). The concentrations of antimony, arsenic, cadmium, copper, mercury, lead, selenium and zinc in fish are presented graphically in Figures 61 to 68 respectively.

Results show that the concentrations of all metals in most species of fish are well (one to two orders of magnitude) below the MPCs. In contrast, the Murray Island sardine *Harengula ovalis* had concentrations of cadmium above the MPC, while concentrations of selenium and possibly arsenic were above or close to the MPC in some individuals. Similarly, an as yet unidentified species known locally as a sardine/hardyhead or kos had concentrations of cadmium and selenium which were above or close to the MPC in some individuals. Three other species showed concentrations of some metals which are close to the MPC (*A. barracuda* [mercury, selenium]; *E. quoyanus* and *L. carponatatus* [arsenic]). The levels of arsenic appear to be relatively high in many species of fish. However, without knowledge of the inorganic:organic arsenic ratio it is not possible to assess how close these concentrations are to the MPC.

The muscle tissue concentrations (mg kg^{-1} wet weight) of antimony, arsenic, cadmium, copper, mercury, lead, selenium and zinc in four species of mollusc (shellfish) from the Torres Strait are presented in Table 14. The concentrations are presented graphically in Figures 69 to 76. Results show that the concentrations of all metals in the cockle *P. erosa* and spider shell *L. lambis* are well below the MPCs. Similarly, the concentrations of antimony, copper, mercury, lead and zinc in the clam *H. hippopus* and red-lipped stromb *S. luhuanus* are relatively low. However, the concentrations of cadmium and, possibly, arsenic in some individuals of *S. luhuanus* are above the MPCs. The concentrations of arsenic, cadmium and selenium in the adductor muscle of *H. hippopus* are close to the MPCs.

The tail muscle concentrations (mg kg^{-1} wet weight) of selected metals from two species of crustacean (both crayfish) from the Torres Strait are presented in Table 15. The concentrations are presented graphically in Figures 77 to 84. Results show that the concentrations of all metals except arsenic are well below the MPCs. The concentrations of arsenic in all individuals of both species of crayfish are likely to exceed the MPC. The concentrations of copper and selenium in some individuals of both species of crayfish are close to the MPCs.

Table 14. Metal concentrations (mean and range (in parentheses) in mg kg^{-1} wet weight) in the soft tissue of four species of mollusc (shellfish).
n = sample size. * Maximum permitted concentration is based on inorganic arsenic only, while concentrations represent total arsenic. ** the mean concentration based on a prescribed number of sampling units. [1] Adductor muscle only.

Species	Location	n	Antimony	Arsenic	Cadmium	Copper	Mercury	Lead	Selenium	Zinc
NMHRC Maximum permitted concentration:			1.50	1.0*	2.0	70.0	0.5**	2.5	1.0	150.0
H. hippopus[1]	Waier Is	1	0.01	9.40	1.10	0.13	0.01	0.02	0.86	1.90
L. lambis	Waier Is	3	0.01	3.40	0.46	2.90	0.01	0.03	0.30	10.1
			(0-0.02)	(3.00-3.70)	(0.13-0.79)	(2.20-4.00)		(0.01-0.02)	(0.03-0.04)	(0.26-
0.33)	(8.2-12.0)									
P. erosa	Boigu Is	17	0.01	0.75	0.02	0.90	0.03	0.05	0.46	34.8
			(0-0.02)	(0.32-1.20)	(0.02-0.02)	(0.38-1.90)		(0.02-0.07)	(0.02-0.11)	(0.28-
0.68)	(11.0-58.0)									
	Daru Is	30	0.01	0.50	0.02	0.86	0.02	0.11	0.22	25.7
			(0-0.02)	(0.18-0.83)	(0.02-0.06)	(0.28-3.50)		(0.02-0.06)	(0.02-0.26)	(0.07-
0.37)	(2.1-53.0)									
	Parama Is	6	0.01	0.58	0.02	5.80	0.02	0.08	0.22	15.3
			(0-0.02)	(0.27-0.96)	(0.02-0.03)	(0.18-32.0)		(0.02-0.03)	(0.03-0.15)	(0.15-
0.38)	(3.9-27.0)									
	Saibai Is	15	0.01	0.56	0.03	0.36	0.02	0.03	0.18	20.7
			(0-0.02)	(0.42-0.91)	(0.02-0.06)	(0.18-0.59)		(0.02-0.03)	(0.02-0.05)	(0.08-
0.28)	(3.3-46.0)									
S. luhanus	Waier Is	3	bdt	10.3	1.80	5.90	0.01	0.04	0.37	7.4
			(7.9-13.0)	(1.40-2.20)	(5.10-6.40)	(0.01-0.02)		(0.03-0.06)	(0.28-0.43)	(6.7-8.2)

Table 15. Metal concentrations (mean and range (in parentheses) in mg kg^{-1} wet weight) in the edible tissue (tail muscle) of two species of crayfish. n = sample size. * Maximum permitted concentration is based on inorganic arsenic only, while concentrations represent total arsenic. ** the mean concentration based on a prescribed number of sampling units.

Species	Location	n	Antimony	Arsenic	Cadmium	Copper	Mercury	Lead	Selenium	Zinc
NMHRC Maximum permitted concentration:			1.5	1.0*	0.2	10.0	0.5**	1.5	1.0	150.0
P. ornatus	Mabuiag Is	1	bdl	37.0	0.01	1.20	0.02	0.03	0.43	18.0
	Yorke Is	3	0.01	45.3	0.03	4.80	0.02	0.02	0.28	28.0
			(0-0.02)	(32.0-56.0)	(0.01-0.05)	(2.70-6.70)	(0.01-0.04)	(bdl-0.03)	(0.26-0.31)	(22.0-33.0)
P. versocolor	Stephen Is	1	0.01	90.0	0.04	8.60	0.02	0.05	0.59	5.0

Table 16. Metal concentrations (mean and range (in parentheses) in mg kg^{-1} wet weight) in tissues of the green turtle (*C. mydas*) from Yam Island and dugong (*D. dugon*) from Boigu Island. n = sample size. [1] muscle, [2] liver, [3] kidney,intestine, [4] muscle, [5] kidney,intestine,liver.

Species	Tissue	n	Antimony	Arsenic	Cadmium	Copper	Mercury	Lead	Selenium	Zinc
NMHRC Maximum permitted concentration:			1.5	1.0	0.05,	10.0	0.03	1.5	1.0	150.0
C. mydas	Intestine	2	0.02	0.31	11.95	0.71	0.01	0.04	0.23	22.5
			(0.01-0.02)	(0.20-0.41)	(4.90-19.0)	(0.69-0.72)	(0.01-0.01)	(0.04-0.04)		(0.09-0.36)
	(19.0-26.0)									
	Kidney	2	0.06	0.43	17.00	23.2	0.02	0.05	0.33	27.2
			(0.04-0.07)	(0.30-0.56)	(12.0-22.0)	(1.30-45.0)	(0.02-0.02)	(0.05-0.05)		(0.27-0.39)
	(26.3-28.0)									
	Liver	2	0.97	1.64	8.50	1.62	0.04	0.59	0.73	35.5
			(0.33-1.6)	(0.87-2.40)	(6.0-11.0)	(0.84-2.40)	(0.03-0.05)	(0.07-1.10)		(0.67-0.78)
	(30.0-41.0)									
	Muscle	2	0.09	0.51	0.04	15.1	0.02	0.02	0.17	16.9
			(0.02-0.15)	(0.26-0.76)	(0.02-0.07)	(0.22-30.0)	(0.02-0.02)	(0.02-0.02)		(0.09-0.25)
	(9.8-24.0)									
D. dugon	Kidney	1	0.01	0.35	17.0	4.4	0.04	0.07	7.90	55.0
	Liver	1	0.14	0.23	4.90	22.0	0.04	0.05	1.40	720.0
	Muscle/fat	1	0.01	0.07	0.03	0.24	bdl	0.02	0.22	7.50

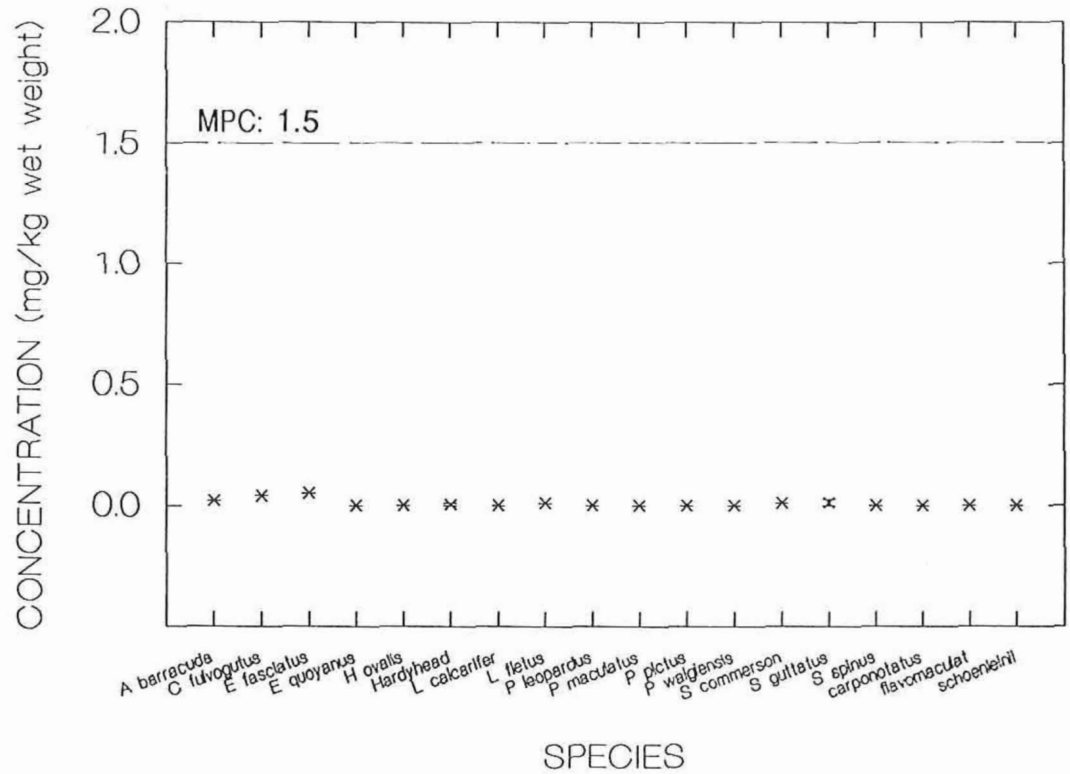

Figure 61. Concentration of antimony in the edible portion of fish from the Torres Strait (mean and range for each species). The NHMRC Maximum Permitted Concentration (MPC) is indicated as a dashed line.

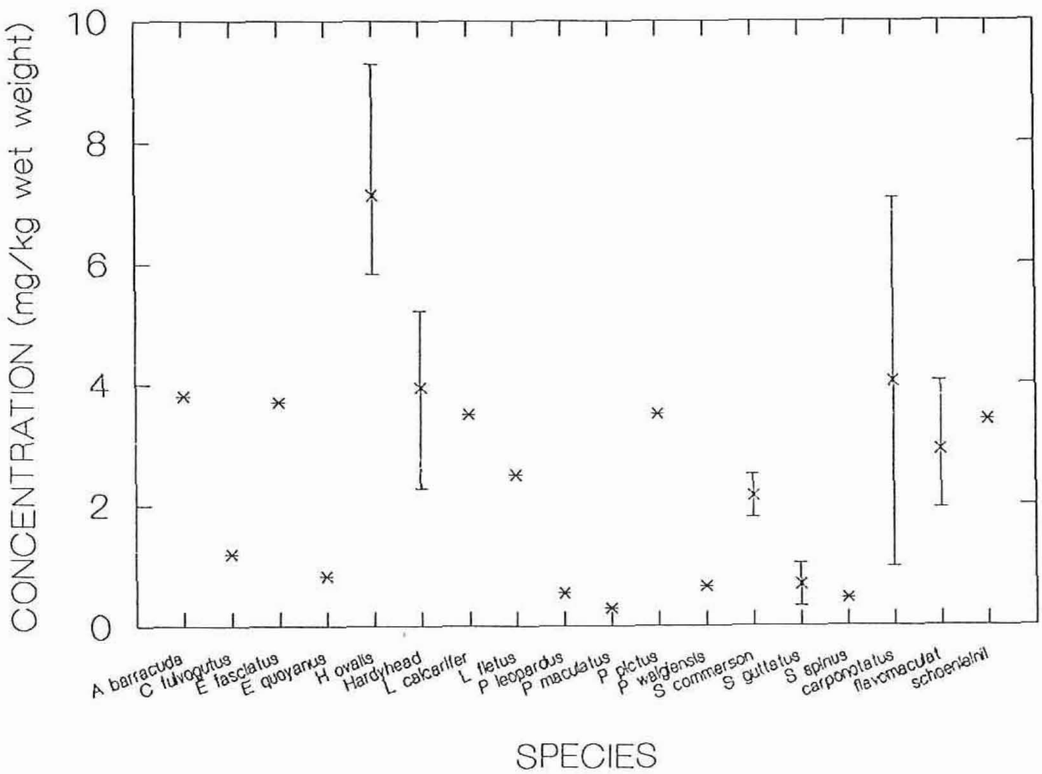

Figure 62. Concentration of total arsenic in the edible portion of fish from the Torres Strait (mean and range for each species).

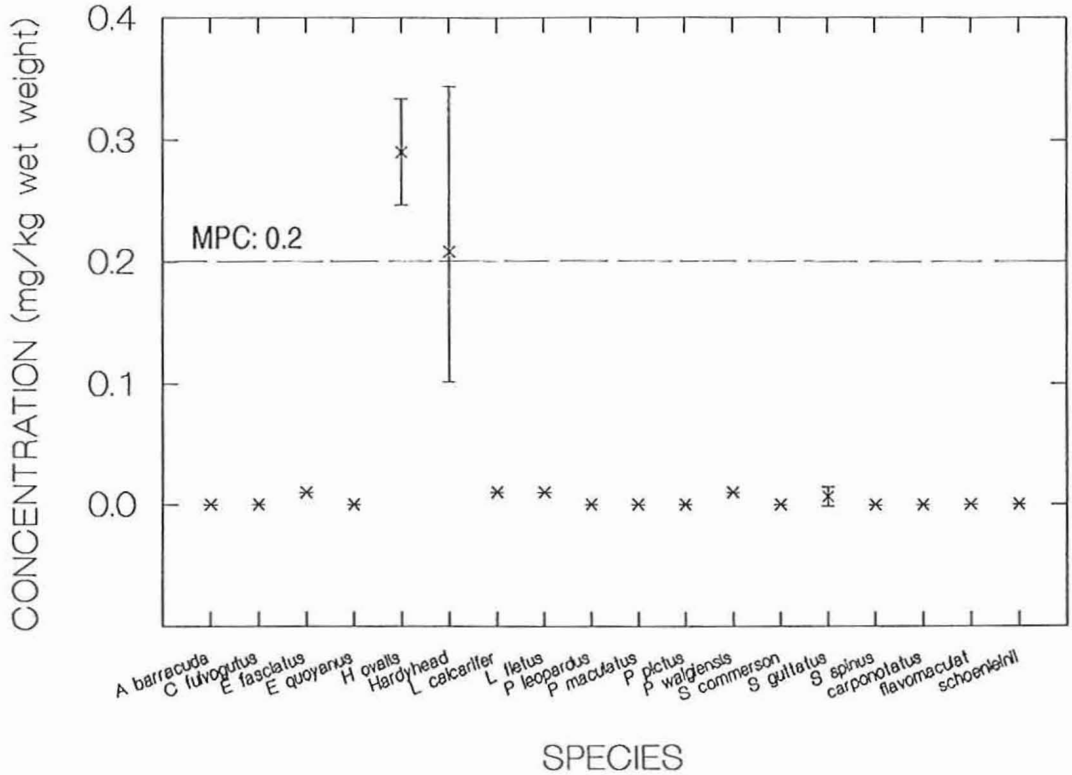

Figure 63. Concentration of cadmium in the edible portion of fish from the Torres Strait (mean and range for each species). The NHMRC Maximum Permitted Concentration (MPC) is indicated as a dashed line.

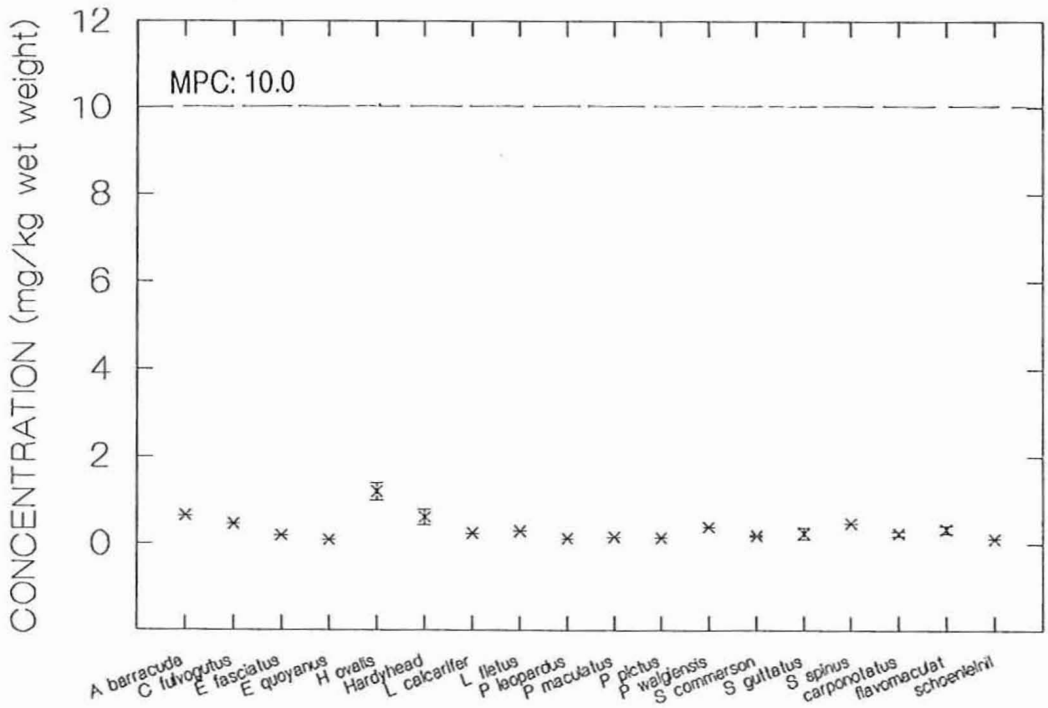

Figure 64. Concentration of copper in the edible portion of fish from the Torres Strait (mean and range for each species). The NHMRC Maximum Permitted Concentration (MPC) is indicated as a dashed line.

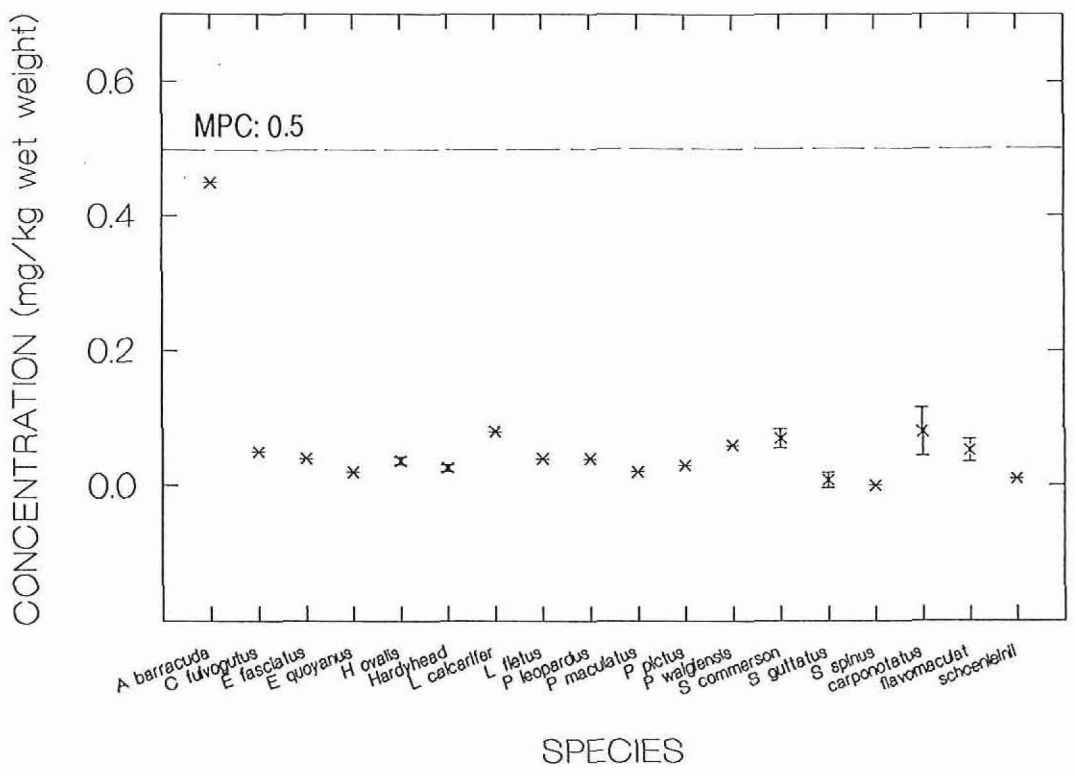

Figure 65. Concentration of mercury in the edible portion of fish from the Torres Strait (mean and range for each species). The NHMRC Maximum Permitted Concentration (MPC) is indicated as a dashed line.

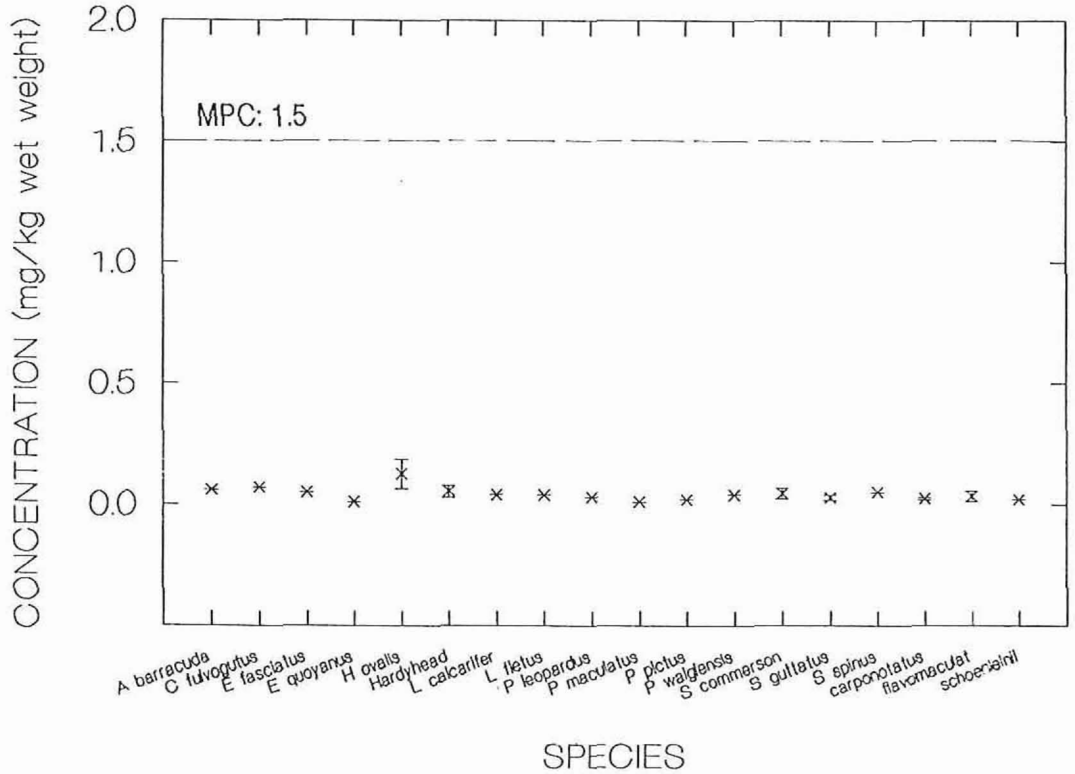

Figure 66. Concentration of lead in the edible portion of fish from the Torres Strait (mean and range for each species). The NHMRC Maximum Permitted Concentration (MPC) is indicated as a dashed line.

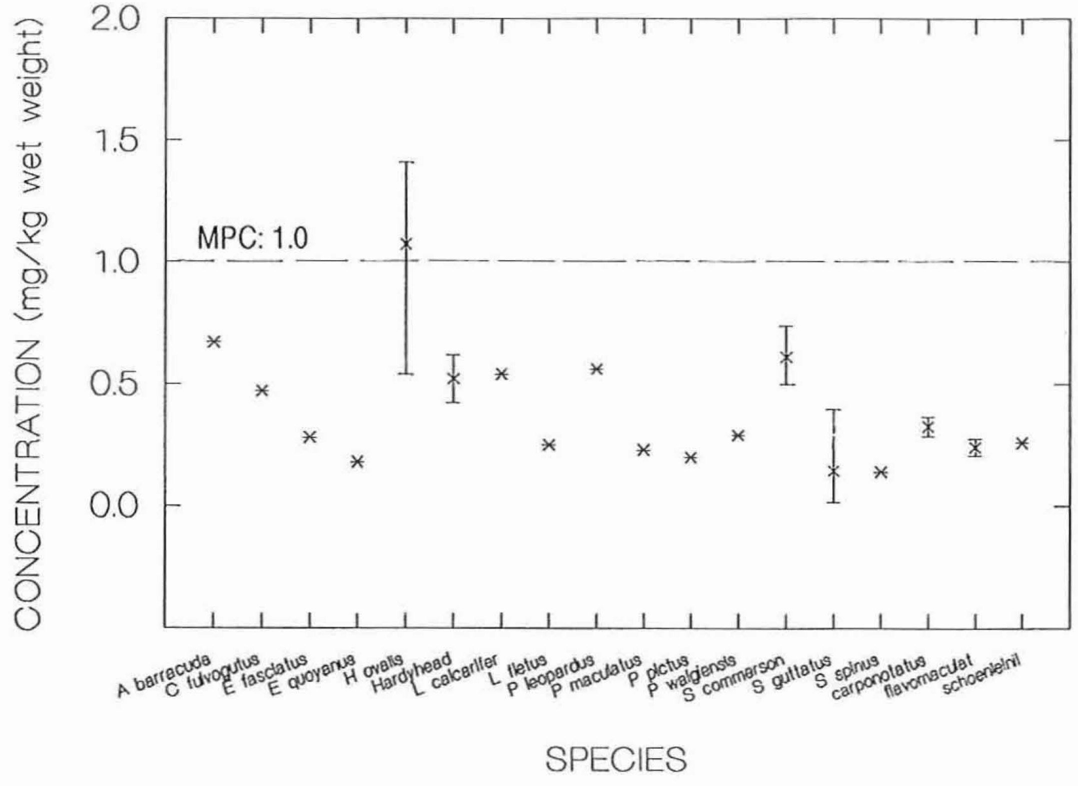

Figure 67. Concentration of selenium in the edible portion of fish from the Torres Strait (mean and range for each species). The NHMRC Maximum Permitted Concentration (MPC) is indicated as a dashed line.

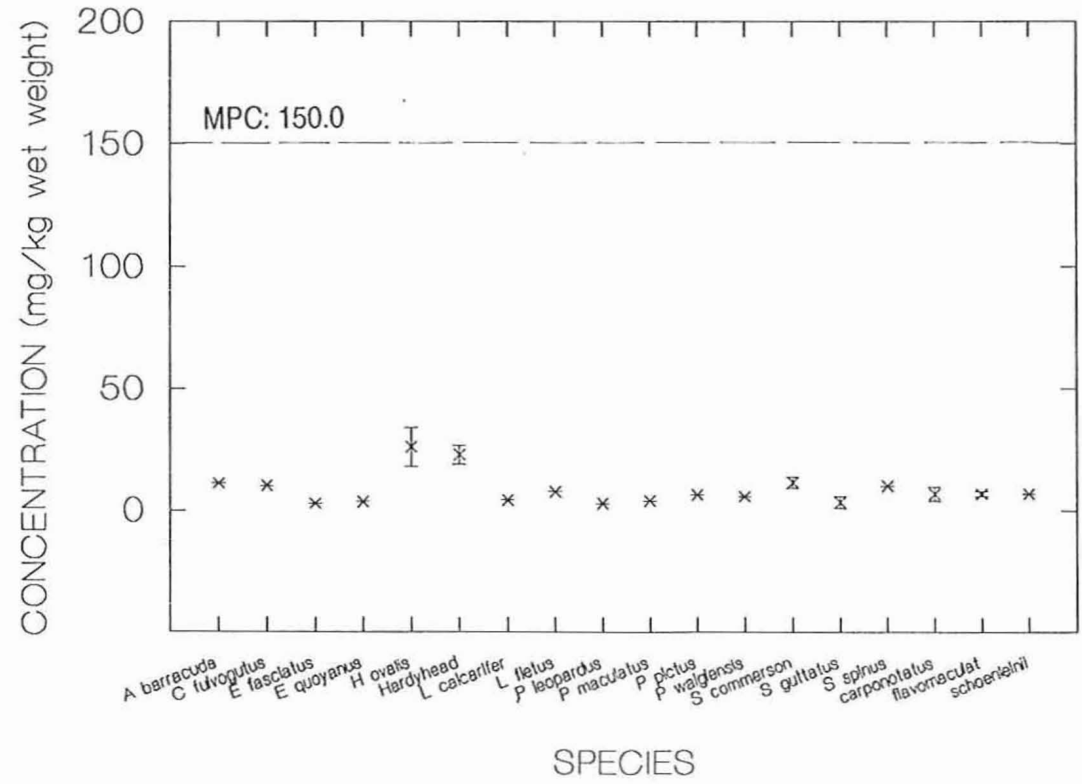

Figure 68. Concentration of zinc in the edible portion of fish from the Torres Strait (mean and range for each species). The NHMRC Maximum Permitted Concentration (MPC) is indicated as a dashed line.

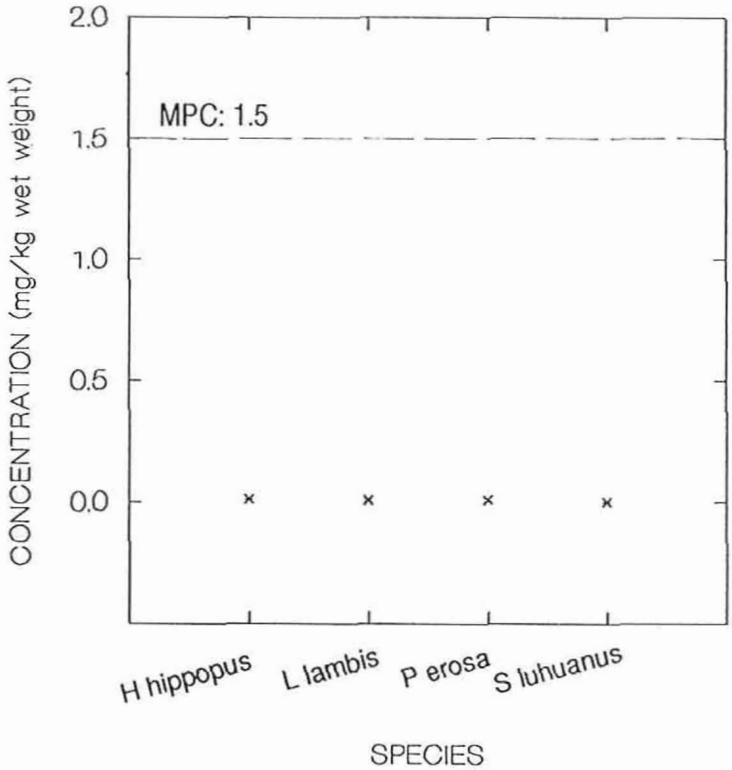

Figure 69. Concentration of antimony in the edible portion of molluscs (shellfish) from the Torres Strait (mean and range for each species). The NHMRC Maximum Permitted Concentration (MPC) is indicated as a dashed line.

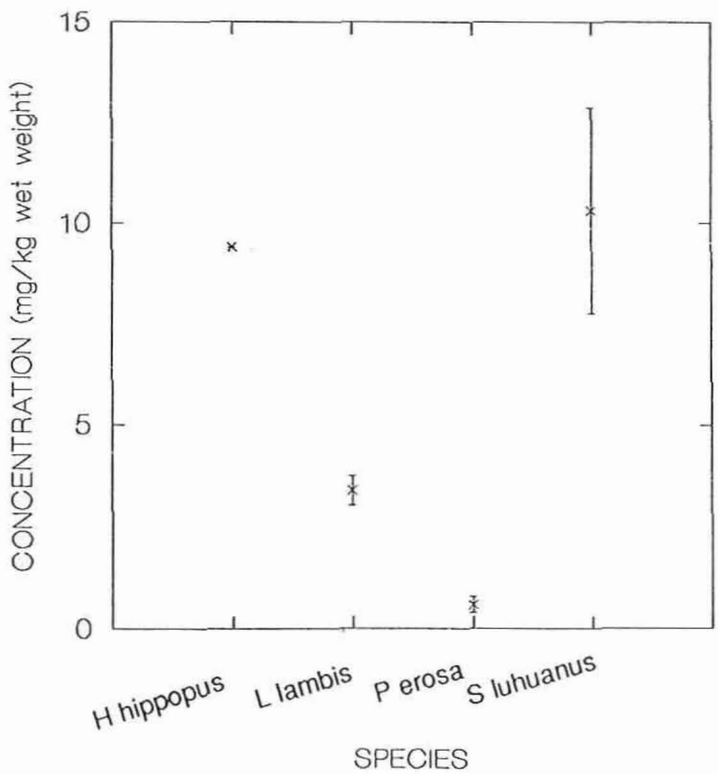

Figure 70. Concentration of arsenic in the edible portion of molluscs (shellfish) from the Torres Strait (mean and range for each species).

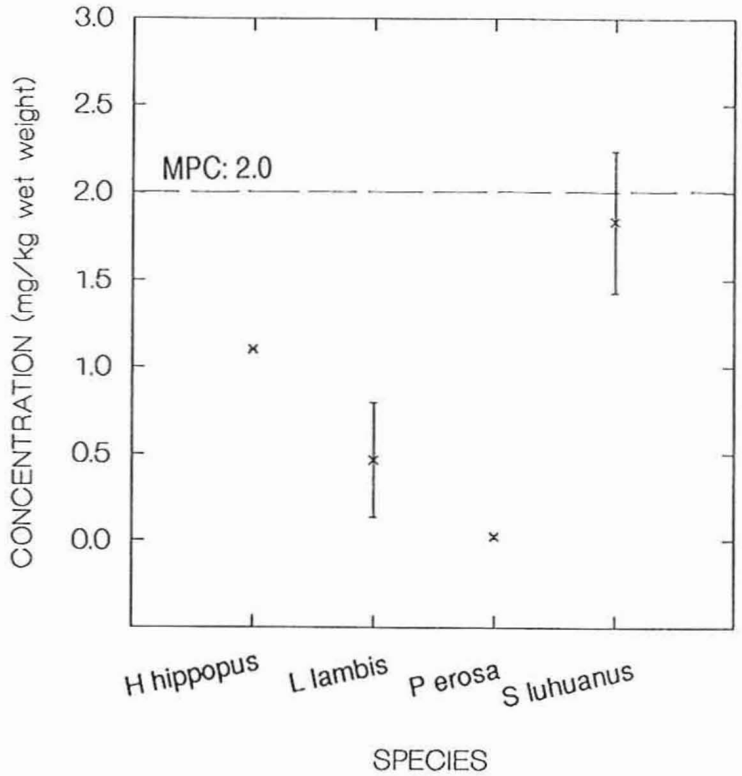

Figure 71. Concentration of cadmium in the edible portion of molluscs (shellfish) from the Torres Strait (mean and range for each species). The NHMRC Maximum Permitted Concentration (MPC) is indicated as a dashed line.

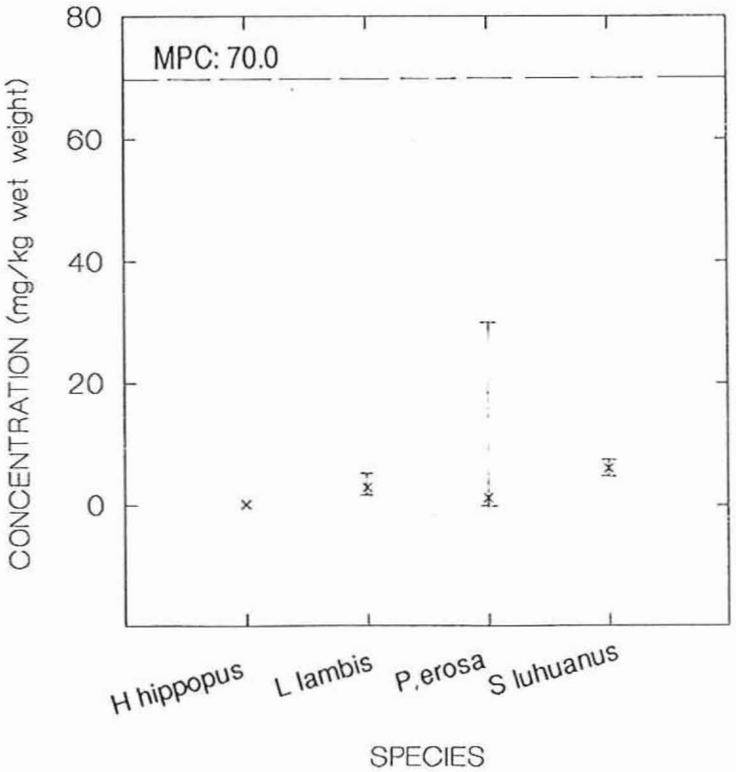

Figure 72. Concentration of copper in the edible portion of molluscs (shellfish) from the Torres Strait (mean and range for each species). The NHMRC Maximum Permitted Concentration (MPC) is indicated as a dashed line.

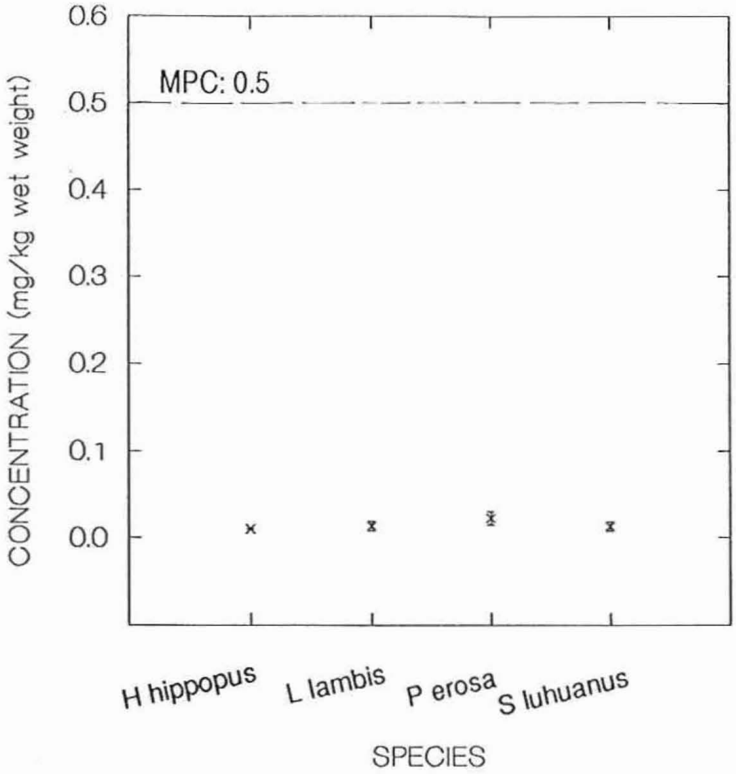

Figure 73. Concentration of mercury in the edible portion of molluscs (shellfish) from the Torres Strait (mean and range for each species). The NHMRC Maximum Permitted Concentration (MPC) is indicated as a dashed line.

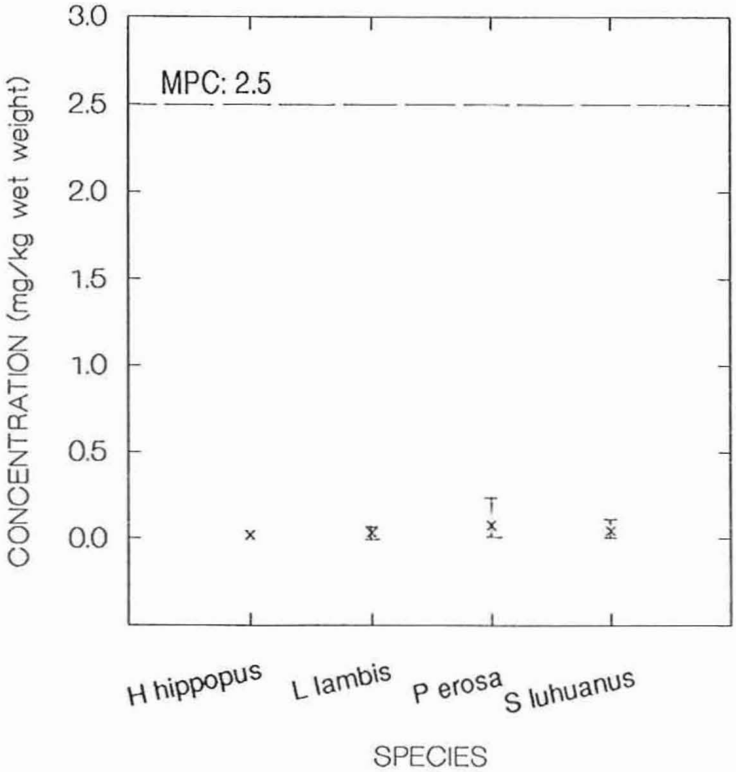

Figure 74. Concentration of lead in the edible portion of molluscs (shellfish) from the Torres Strait (mean and range for each species). The NHMRC Maximum Permitted Concentration (MPC) is indicated as a dashed line.

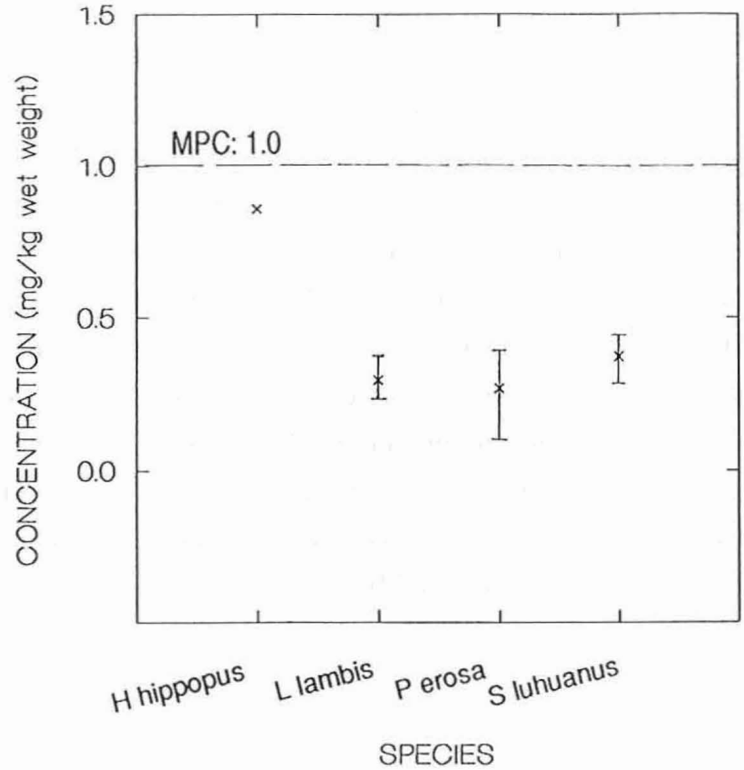

Figure 75. Concentration of selenium in the edible portion of molluscs (shellfish) from the Torres Strait (mean and range for each species). The NHMRC Maximum Permitted Concentration (MPC) is indicated as a dashed line.

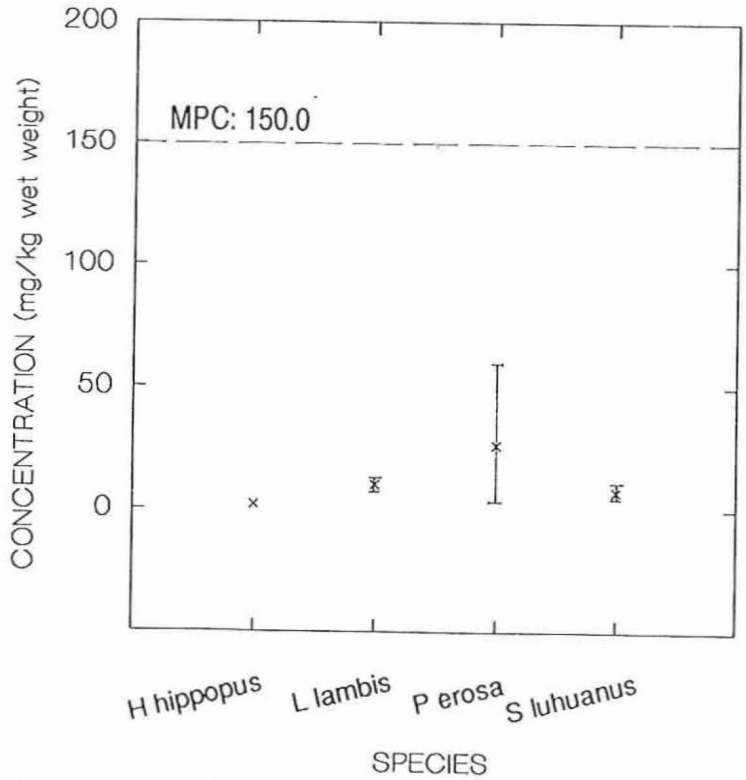

Figure 76. Concentration of zinc in the edible portion of molluscs (shellfish) from the Torres Strait (mean and range for each species). The NHMRC Maximum Permitted Concentration (MPC) is indicated as a dashed line.

Tissue concentrations (mg kg^{-1} wet weight) of selected metals from the green turtle *C. mydas* and dugong *D. dugon* from the Torres Strait are presented in Table 16 (see p.107). The concentrations are presented graphically in Figures 85 to 92. The MPC for arsenic in food other than fish, molluscs and crustaceans is based on total arsenic. In the NHMRC food standards meat and edible offal are specified as coming from cattle, buffalo, sheep, pig, goat, deer, rabbit, hare or poultry (G Rayment; pers. comm.). For the case of dugong and turtle, where no standard exists, the MPC for the 'all other foods' category was applied. Results show that the concentration of cadmium in all the visceral tissues of the green turtle *C. mydas* and dugong *D. dugon* far exceeds the MPC for this metal in food. Similarly, the concentrations of mercury and selenium in the kidney of *D. dugon*, mercury in the liver of *D. dugon*, and cadmium in the muscle tissue of one individual of *C. mydas* exceed the MPCs.

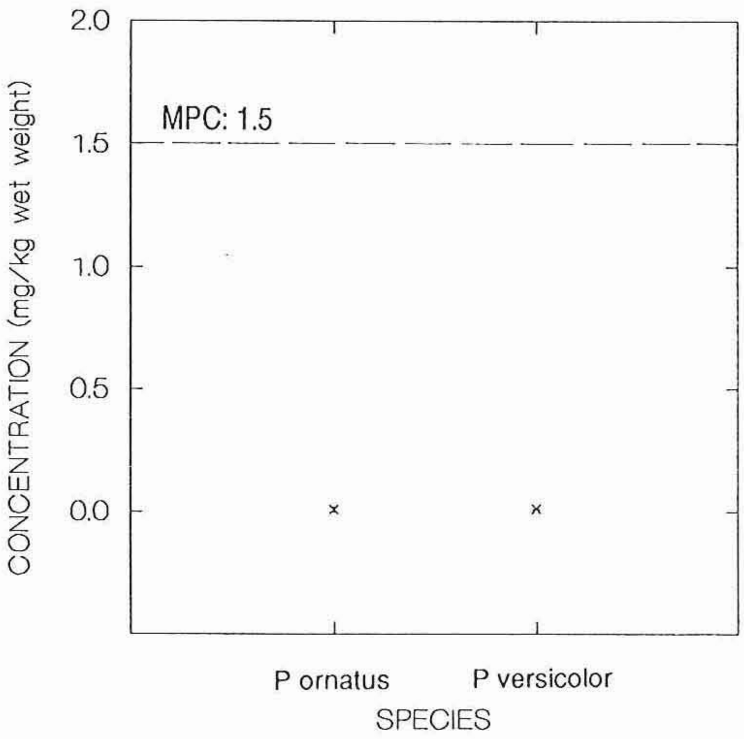

Figure 77. Concentration of antimony in the edible portion (tail muscle) of two species of crayfish from the Torres Strait (mean and range for each species). The NHMRC Maximum Permitted Concentration (MPC) is indicated as a dashed line.

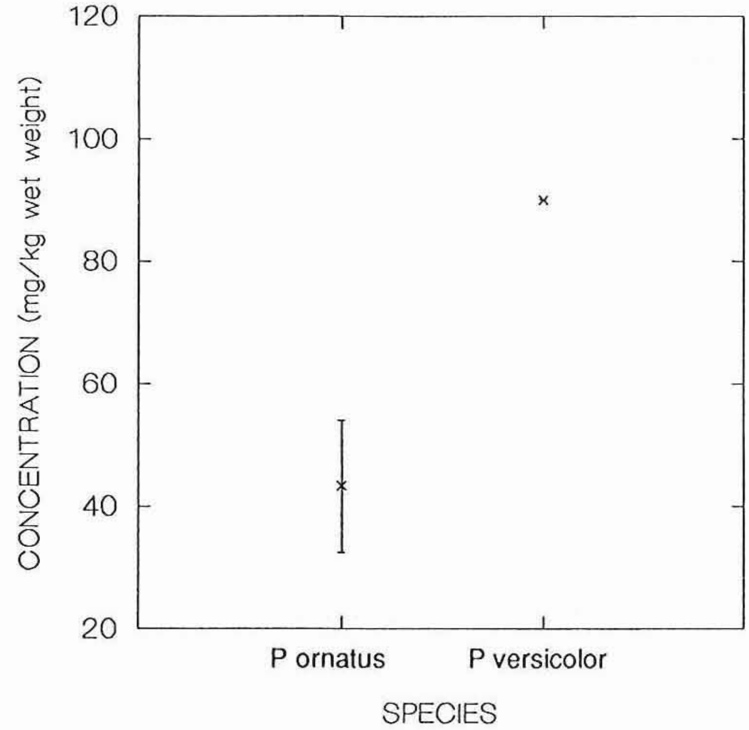

Figure 78. Concentration of arsenic in the edible portion (tail muscle) of two species of crayfish from the Torres Strait (mean and range for each species).

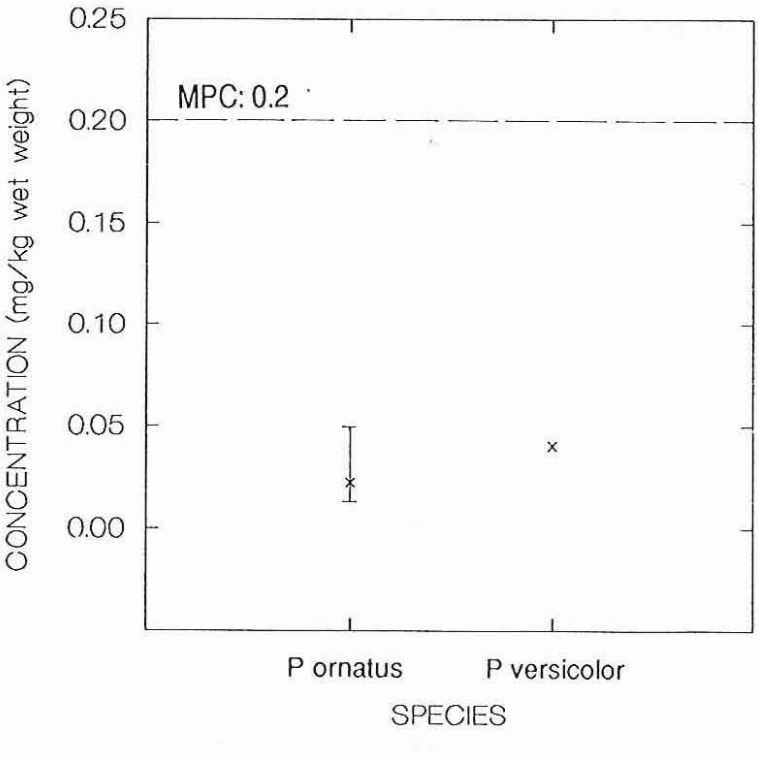

Figure 79. Concentration of cadmium in the edible portion (tail muscle) of two species of crayfish from the Torres Strait (mean and range for each species). The NHMRC Maximum Permitted Concentration (MPC) is indicated as a dashed line.

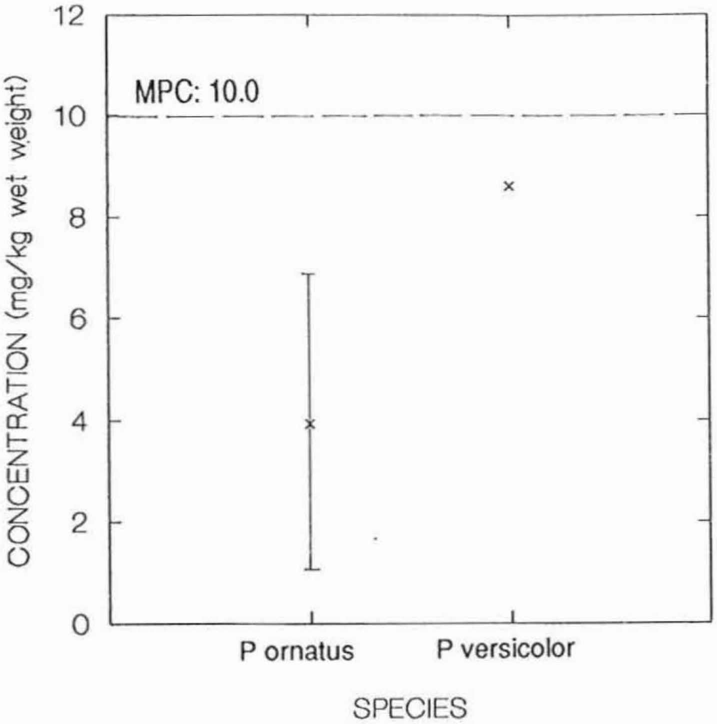

Figure 80. Concentration of copper in the edible portion (tail muscle) of two species of crayfish from the Torres Strait (mean and range for each species). The NHMRC Maximum Permitted Concentration (MPC) is indicated as a dashed line.

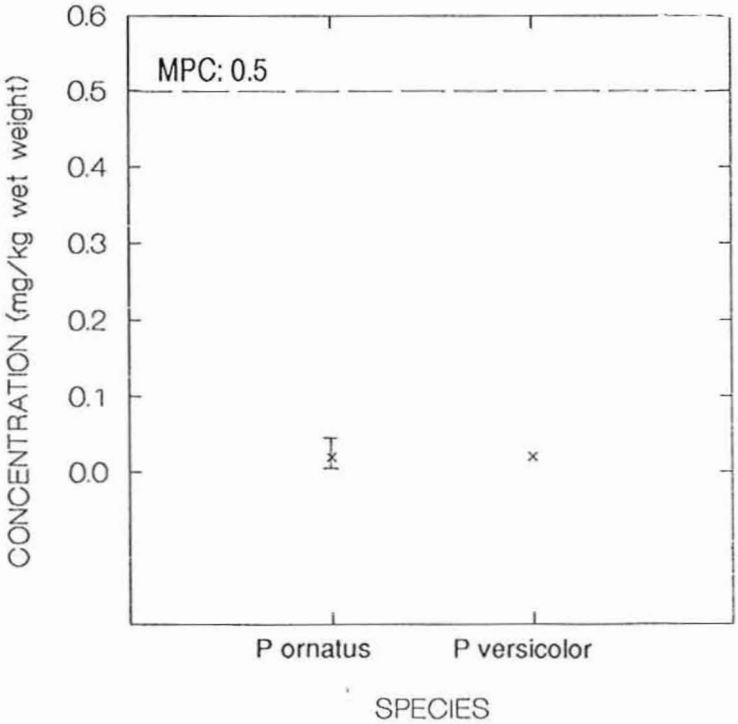

Figure 81. Concentration of mercury in the edible portion (tail muscle) of two species of crayfish from the Torres Strait (mean and range for each species). The NHMRC Maximum Permitted Concentration (MPC) is indicated as a dashed line.

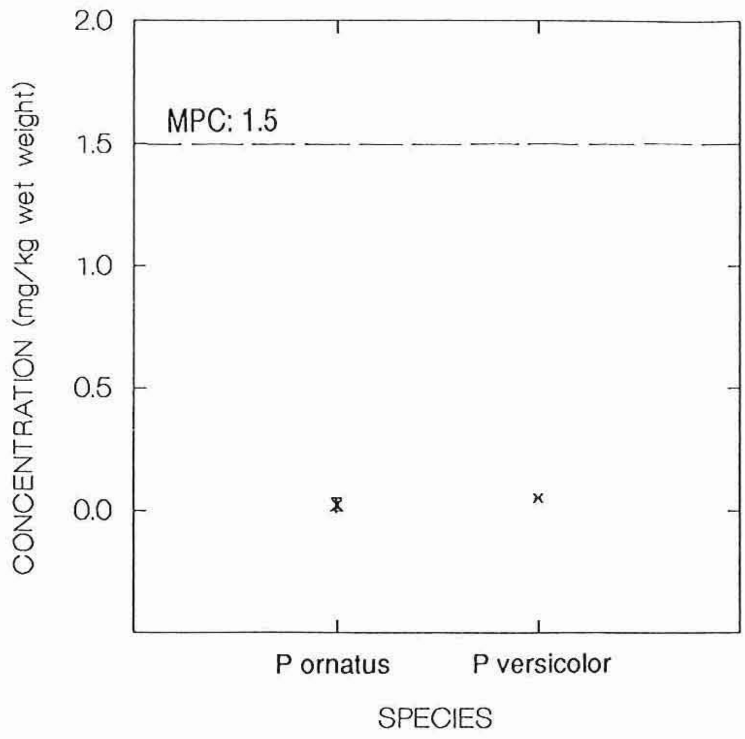

Figure 82. Concentration of lead in the edible portion (tail muscle) of two species of crayfish from the Torres Strait (mean and range for each species). The NHMRC Maximum Permitted Concentration (MPC) is indicated as a dashed line.

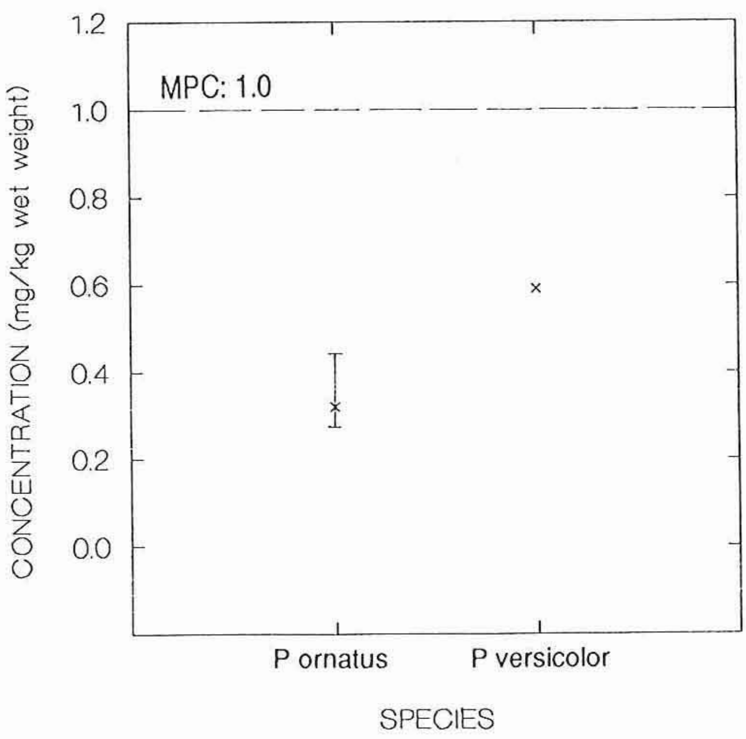

Figure 83. Concentration of selenium in the edible portion (tail muscle) of two species of crayfish from the Torres Strait (mean and range for each species). The NHMRC Maximum Permitted Concentration (MPC) is indicated as a dashed line.

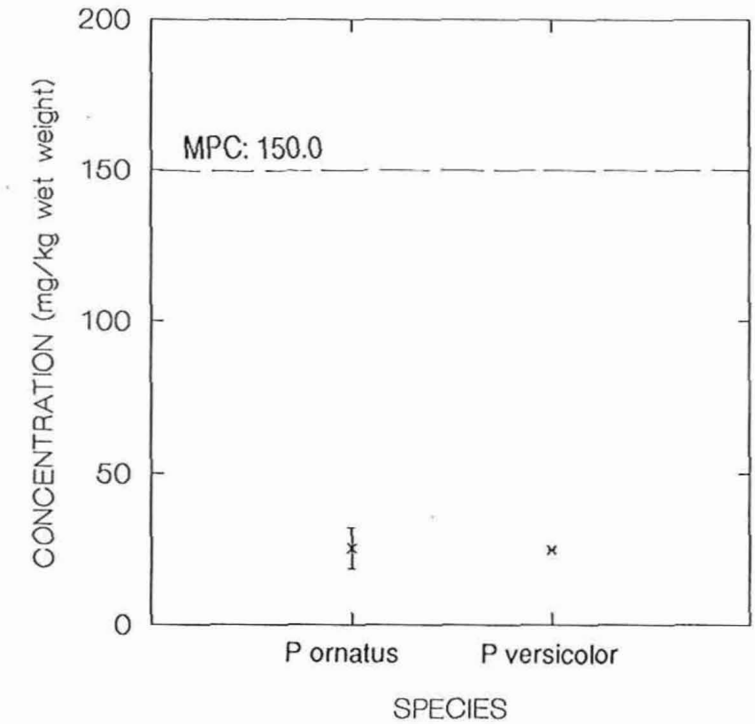

Figure 84. Concentration of zinc in the edible portion (tail muscle) of two species of crayfish from the Torres Strait (mean and range for each species). The NHMRC Maximum Permitted Concentration (MPC) is indicated as a dashed line.

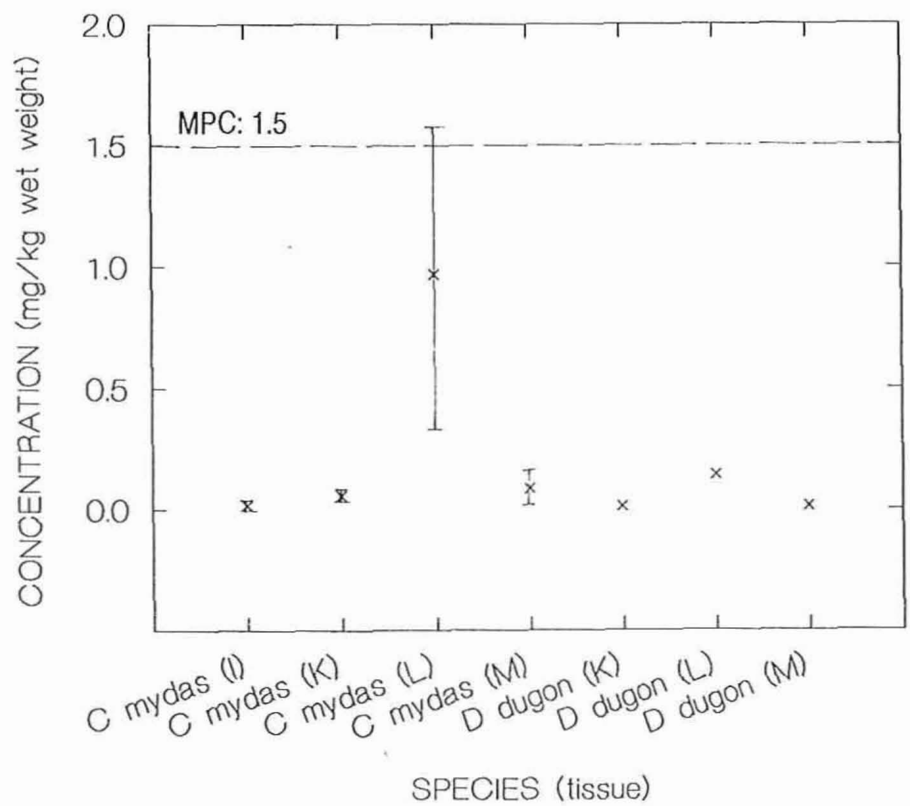

Figure 85. Concentration of antimony in the edible portion (various tissues - (I) intestine, (K) kidney, (L) liver, (M) muscle) of turtle (*C. mydas*) and dugong (*D. dugon*) from the Torres Strait (mean and range for each species). The NHMRC Maximum Permitted Concentration (MPC) is indicated as a dashed line.

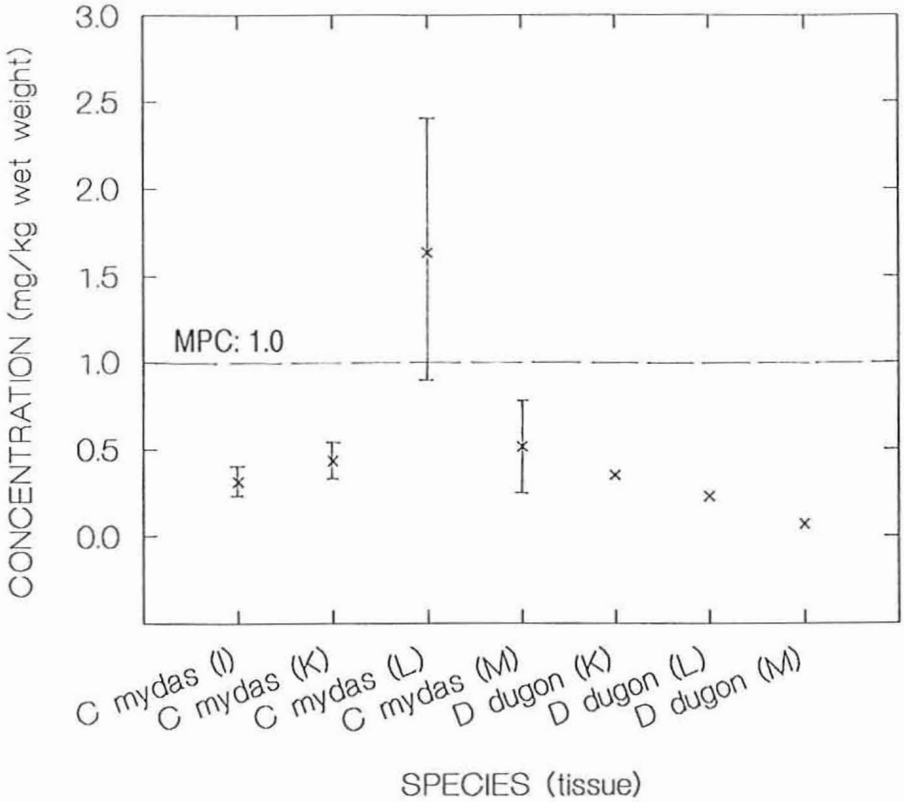

Figure 86. Concentration of arsenic in the edible portion (various tissues - (I) intestine, (K) kidney, (L) liver, (M) muscle) of turtle (*C. mydas*) and dugong (*D. dugon*) from the Torres Strait (mean and range for each species).

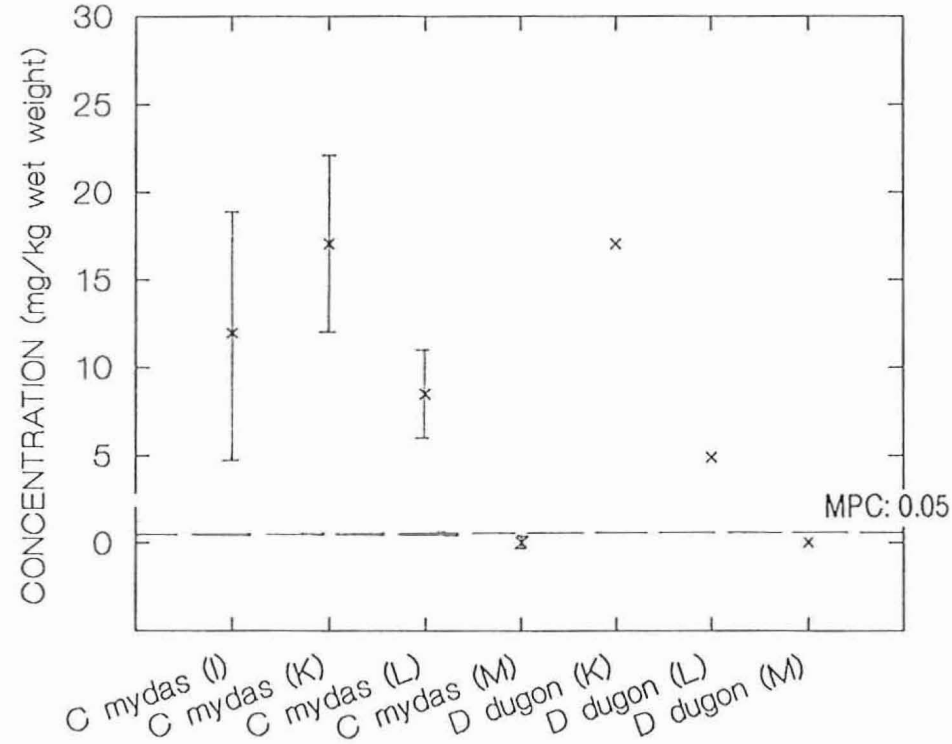

Figure 87. Concentration of cadmium in the edible portion (various tissues - (I) intestine, (K) kidney, (L) liver, (M) muscle) of turtle (*C. mydas*) and dugong (*D. dugon*) from the Torres Strait (mean and range for each species). The NHMRC Maximum Permitted Concentration (MPC) is indicated as a dashed line.

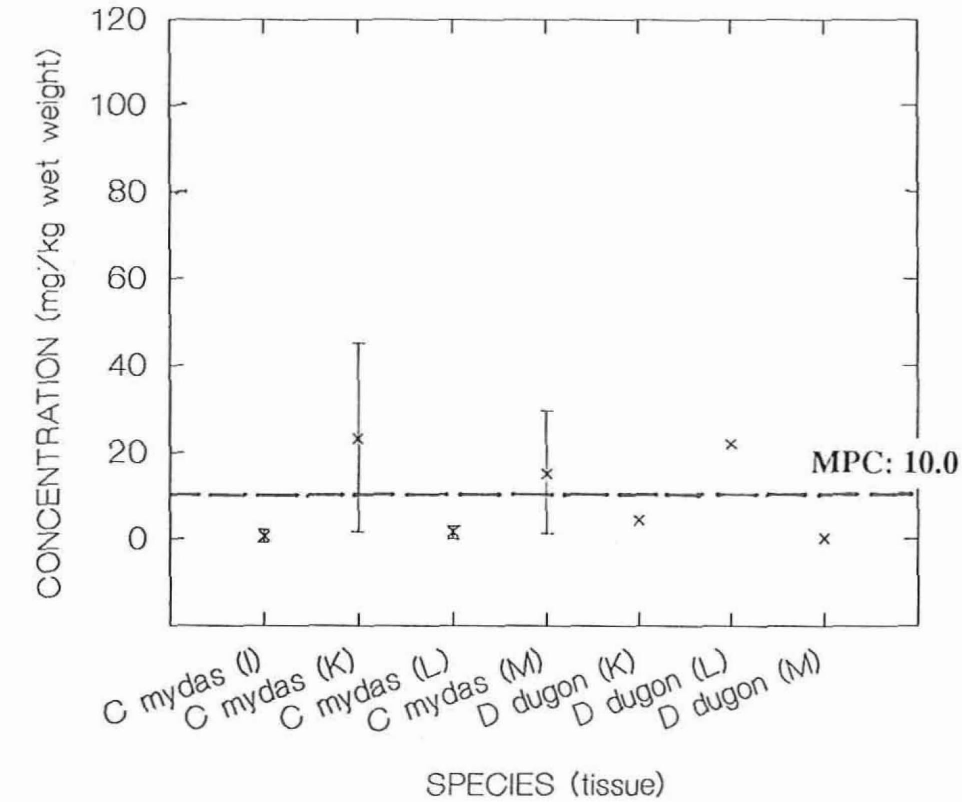

Figure 88. Concentration of copper in the edible portion (various tissues - (I) intestine, (K) kidney, (L) liver, (M) muscle) of turtle (*C. mydas*) and dugong (*D. dugon*) from the Torres Strait (mean and range for each species). The NHMRC Maximum Permitted Concentration (MPC) is indicated as a dashed line.

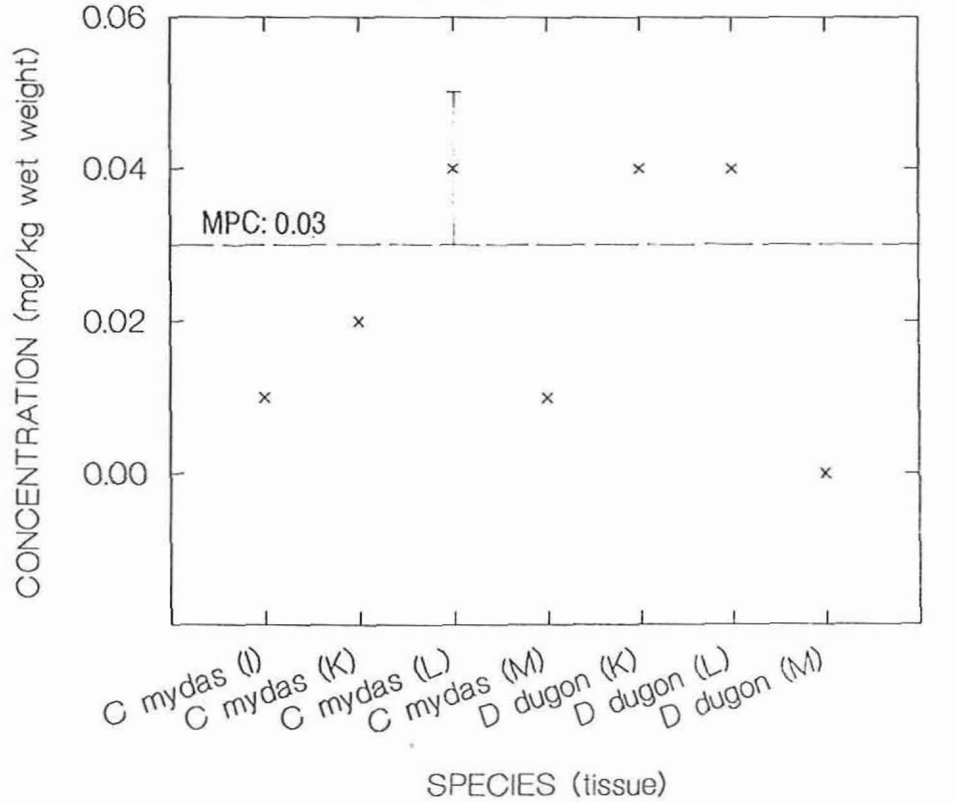

Figure 89. Concentration of mercury in the edible portion (various tissues - (I) intestine, (K) kidney, (L) liver, (M) muscle) of turtle (*C. mydas*) and dugong (*D. dugon*) from the Torres Strait (mean and range for each species). The NHMRC Maximum Permitted Concentration (MPC) is indicated as a dashed line.

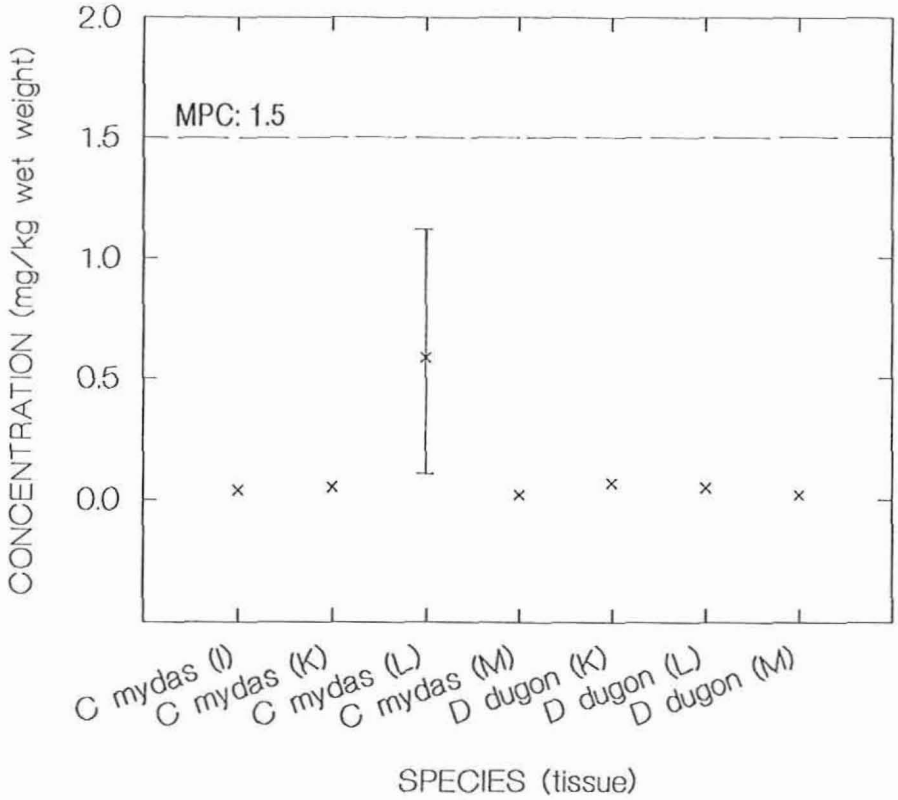

Figure 90. Concentration of lead in the edible portion (various tissues - (I) intestine, (K) kidney, (L) liver, (M) muscle) of turtle (*C. mydas*) and dugong (*D. dugon*) from the Torres Strait (mean and range for each species). The NHMRC Maximum Permitted Concentration (MPC) is indicated as a dashed line.

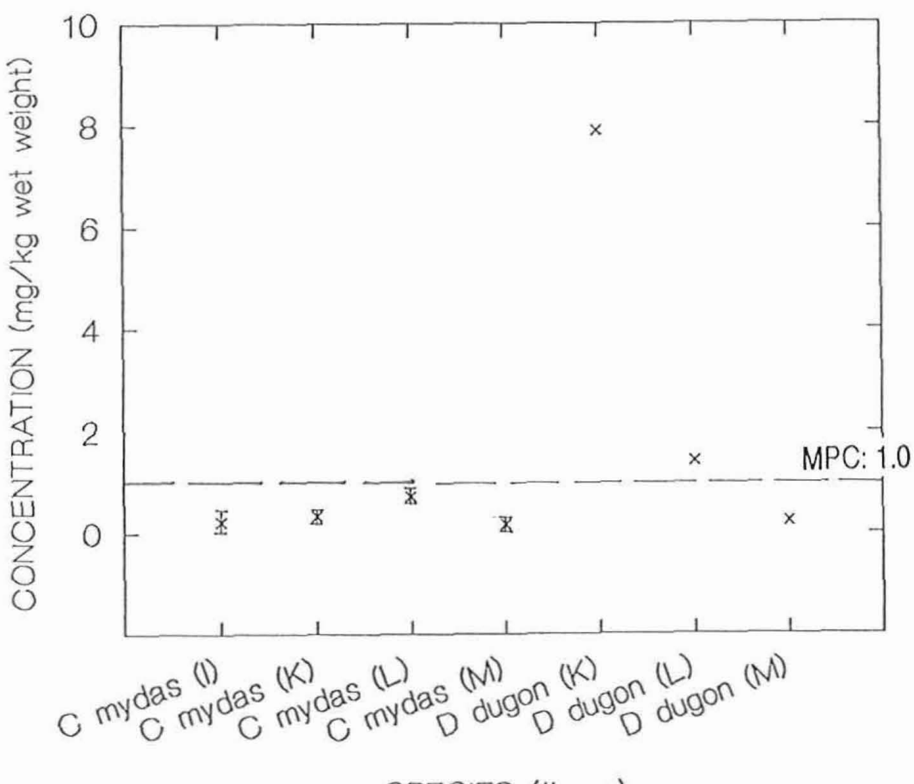

Figure 91. Concentration of selenium in the edible portion (various tissues - (I) intestine, (K) kidney, (L) liver, (M) muscle) of turtle (*C. mydas*) and dugong (*D. dugon*) from the Torres Strait (mean and range for each species). The NHMRC Maximum Permitted Concentration (MPC) is indicated as a dashed line.

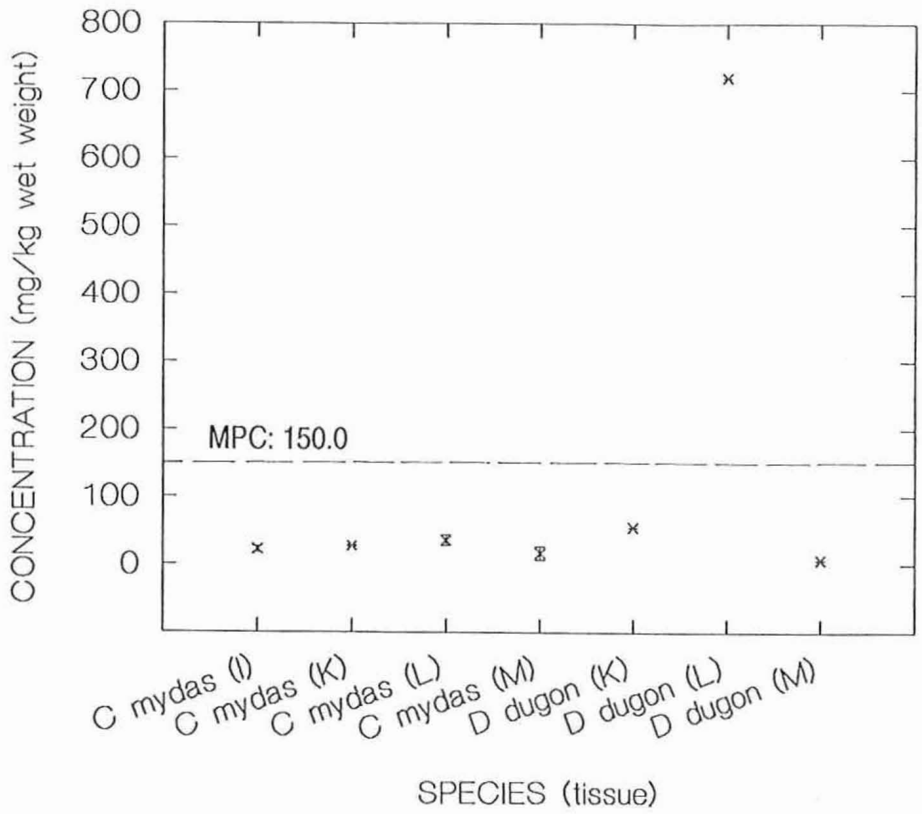

Figure 92. Concentration of zinc in the edible portion (various tissues - (I) intestine, (K) kidney, (L) liver, (M) muscle) of turtle (*C. mydas*) and dugong (*D. dugon*) from the Torres Strait (mean and range for each species). The NHMRC Maximum Permitted Concentration (MPC) is indicated as a dashed line.

DISCUSSION

Seasonal and Spatial Patterns

Early oceanographic studies in the Torres Strait and Gulf of Papua identified a tongue of brackish water, originating principally from the Fly River, which entered the Torres Strait through the Great North East Passage (Wolanski & Ruddick, 1981; Wolanski et al., 1984; Wolanski, 1991). This was thought to be an almost permanent feature of the region (Wolanski et al., 1984; Wolanski, 1991). Current reversals, in a roughly north-south direction, driven by local winds were thought to periodically flush the brackish water out of the Great North East Passage and central Torres Strait.

Surface salinity contours (Wolanski et al., 1984) indicate that the region of influence was largely limited to the northern portion of the Great North East Passage and Torres Strait during the study periods and that the plume was only slightly less saline than background values in central Torres Strait and northern GBR waters. During these periods, brackish water was not always limited to the eastern side of the Warrior Reefs. Missionary Passage was identified as a pathway for the transport of brackish water from the Fly River and Gulf of Papua to the western side of the Warrior Reefs

(Wolanski et al., 1984; Wolanski, 1991). However, coastal waters from Irian Jaya have been identified as another possible source of the brackish water which has been observed to the west of the Warrior Reefs, particularly during the monsoon period when coastal currents appear to flow eastwards along the Irian Jaya/Papua New Guinea coast (Mulhearn, 1989; Wolanski & Ridd, 1990; Wolanski, 1991).

A more recent oceanographic and sediment transport study in the northern Torres Strait, western Gulf of Papua and Fly River estuary (Wolanski & Eagle, 1991; Wolanski et al., 1992a,b,c,d), which focuses specifically on the fate of Fly River discharge, reveals a more complex picture with seasonal differences in the degree of influence of river discharge on the northern Torres Strait (Wolanski et al., 1992b). Wolanski et al. (1992b) report that seasonal variation in wind forcing has a dominant influence on circulation patterns in the Gulf of Papua resulting in a significant brackish water intrusion into the Torres Strait via the Great North East Passage during the monsoon period when north-westerly winds prevail. Analysis of 40 years of wind records from Thursday Island indicates that these north-westerly monsoon winds prevail from December to March (Dight, 1991). The intrusion is thought to be less prevalent during the trade wind season during which plumes do not extend as far off-shore. Model results, which show that most discharge from the Fly River is towards the north-east and into the Gulf of Papua, are consistent with the findings of Harris (1991) who suggests that only about 2% of the annual sediment discharge from the Fly River is deposited in the Torres Strait, while a large proportion is probably deposited in the Gulf of Papua.

Sediments

Results from the present study show that the Fly River is, nevertheless, the major source of fine-grained sediment of terrigenous origin to the northern Torres Strait. This sediment is an important source of a suite of major and trace metals including aluminium, cobalt, chromium, copper, iron, manganese, nickel, lead, silica and zinc, all of which are in relatively high concentrations at locations closest to the mouth of the Fly River. There is evidence of a seasonal increase in the concentrations of some metals which are associated with river discharge (Co,Ni,Si) in the northern Torres Strait during the monsoon season. This is consistent with the oceanographic studies which indicate that the influence of Fly River discharge on the northern Torres Strait is greatest during the monsoon period. However, there are also some inconsistencies with respect to this scenario (e.g. aluminium and lead concentrations which were higher at station S10 during the pre-monsoon season). Sediments appear to integrate metal concentrations fairly well over periods of months as there are relatively few significant differences among seasons. Everaarts (1989) also found only minor differences in trace metal concentrations in both bulk sediment and the silt fraction among wet and dry seasons in coastal areas around East Java.

Sediment samples show that arsenic, cadmium, magnesium, mercury and selenium are not primarily associated with terrigenous sediments and their concentrations, therefore, are not likely to have been significantly influenced by Fly River discharge. Cadmium and magnesium, in particular, are primarily associated with coarse-grained carbonates of marine origin while arsenic, mercury and selenium are not strongly correlated with any particular sediment type.

A relatively steep gradient in the concentrations of those trace metals that are associated with Fly River discharge is evident moving away from the Fly River mouth and towards the central Torres Strait. The western-most (S3 and S4), central (S5) and eastern-most (S7) sampling stations display little, if any, influence of river discharge. The concentrations of trace metals associated with terrigenous sediment (Al,Co,Cr,Cu,Fe,Mn,Ni,Pb,Si and Zn) are relatively low at these locations. Terrigenous sediments and their associated trace metals appear to be mostly restricted to the northern Torres Strait adjacent to the Papua New Guinea coast (stations S1,S10,S2 and S6). These results are consistent with previous oceanographic and sedimentation studies identified above which indicate that the region of Fly River influence is largely limited to the northern portion of the Great North East Passage and Torres Strait but may extend to the west along the Papua New Guinea coast through Missionary Passage.

The very large variations in the concentrations of many metals among sampling stations in the Torres Strait is evidently a consequence of differences in the grain-size composition of sediments. Normalization procedures are used specifically to compensate for granular variability (Loring, 1991). Aluminium- and <200 μm-normalized trace metal concentrations indicate that cobalt, chromium, copper, iron, manganese, nickel and lead, all of which are major constituents of Fly River sediment, are in higher concentrations away from the Fly River delta on the western side of the Torres Strait. Only normalized zinc concentrations did not vary significantly among sampling locations along the Papua New Guinea coast from east to west. Oceanographic studies of the Gulf of Carpentaria and Irian Jaya region (e.g. Wolanski & Ridd, 1990) have found that water flows northwards along the western side of the Torres Strait during the trade wind season and eastwards from Irian Jaya along the

Papua New Guinea coast during the monsoon season (Wolanski, 1991). On this basis, it would appear that there is a major source of trace metals further to the west, possibly in Irian Jaya, or along the west coast of Cape York peninsula. It is anticipated that the results of the main study should shed further light on this finding.

Biota

The bioaccumulation of trace metals is complex and, except in relatively few instances, appears not to be particularly well understood (Depledge & Rainbow, 1990). A knowledge of metal speciation, which is particularly complex in coastal environments where there are interactions between fresh and sea water, is evidently fundamental to a thorough understanding of accumulation and metabolism of trace metals by organisms. Sediments, free metal ions and food are generally recognized as the principal sources of trace metals to biota.

Free metal ions are the most biologically available inorganic forms in seawater where their concentration is largely dependent on salinity and pH (Bryan, 1984). However, Bryan (1984) notes that while trace metals associated with sediments are generally thought to have much lower bio-availability than soluble species of metals, the much higher concentrations of sediment-bound forms can be important sources to some organisms and to the soluble fraction under changing physico-chemical conditions. Organic complexation can also become important in such coastal environments and contribute significantly to the total ion concentration.

Metals associated with the surfaces of sediment particles and complexed by humics are known to be the primary source of metals to deposit feeding bivalves (Bryan, 1984). Sediment particles and the interstitial water of ingested sediment is also likely to be the principal source of trace metals to the sea cucumber *S. chloronotus*. In contrast, passive absorption of free metal ions is the source of trace metals in phytoplankton and marine algae (Bryan, 1984). Free metal ions are believed to be the principal bio-available form of metal that is acquired by the Tridacnid clams *T. crocea* and *T. maxima* as they obtain their nutritional requirements mostly from the uptake of dissolved material via the gills and by direct transfer from symbiotic zooxanthellae (Fankboner & Reid, 1990). Studies on metal accumulation and depuration in *T. crocea* by Denton and Heitz (1991) demonstrate that changes in the concentrations of cadmium, copper, lead, mercury and zinc in the kidney reflect different dissolved environmental concentrations.

In the case of marine angiosperms, including the seagrasses *T. hemprichii* and *T. ciliatum* which are rooted into the sediment, there is the potential for absorption both from the sediment and water column (as ions). However, there is little evidence that sediments contribute significantly to trace metal concentrations in the leaves except possibly in heavily polluted sediments (Driftmeyer et al., 1980). Rather, in some species cadmium ions are absorbed by the leaves and translocated to the root-rhizome (Faraday & Churchill, 1979; Bryan, 1984). In other species, however, there is uptake and accumulation of cadmium ions by the root-rhizome from interstitial water (Fabris et al., 1982).

Bryan (1984) notes that there is a considerable body of evidence which indicates that particulates, rather than dissolved ions, are the principal source of metals in most bivalve molluscs, particularly oysters. Clearly, however, experimental studies have shown that dissolved ions can contribute to the total body burden of oysters (e.g. Zaroogian, 1979,1980). Metal concentrations in the bivalve molluscs *P. margaritifera*, *H. hyotis*, *C. plinthota* and *P. erosa* are likely to reflect particulate concentrations in the environment, both organic and inorganic, and to a lesser extent dissolved ions. Arsenic though is thought to be almost exclusively derived from food sources such as phytoplankton (Zaroogian & Hoffman, 1982). The cockle *P. erosa* is known to be a relatively unspecialized suspension feeder which uses its gills to filter particulate material from the water column (Morton, 1983) but has not been studied previously as an indicator of variation in environmental trace metal concentrations.

Food is also believed to be the main source of trace metals in gastropod molluscs, such as *T. niloticus* and *S. luhuanus*, and fish, such as *L. carponotatus* (Bryan, 1984). In the latter case however, some absorption via the gills has been reported.

Results from the present study for *T. crocea* show strong seasonal increases in the bio-availablity of many metals, primarily arsenic, cadmium, cobalt, copper, nickel, lead, strontium, uranium and zinc, from sampling locations at the northern end of the Great North East Passage (Kokope Reef and Campbell Island) following the monsoon season. These two locations both appear to be influenced by brackish water originating from coastal rivers, including the Fly, during the monsoon period in particular. This seasonal increase at Kokope Reef is not evident in the concentrations of cadmium, copper, strontium and zinc at Aureed Island (which lies in the central Torres Strait and southern end of the Great North East Passage) where brackish coastal waters have marginal influence. Increases in arsenic, cobalt, nickel, lead and uranium concentrations are evident at all sampling locations. In contrast, the concentrations of aluminium, mercury and selenium decrease at all sampling locations following the monsoon period.

Changes in the concentrations of cadmium, copper, strontium and zinc in the kidney tissue of *T. crocea*, which occurred only at the northern-most locations, appear therefore to be related to coastal runoff and to have resulted from: (1) increased concentrations of these metals derived from river discharge; and/or (2) physico-chemical changes in the watermass leading to increases in (a) the bio-available portion of the metals only and/or (b) metal kinetics within biota. Changes in the concentrations of aluminium, arsenic, cobalt, mercury, nickel, lead, selenium and uranium over the monsoon period are presumably unrelated to coastal runoff as they occur at all sampling locations.

Much more limited datasets are available from the present study for the four remaining species, *T. maxima*, *P. margaritifera*, *T. niloticus* and *L. carponotatus*, that were collected from reefs in the northern and central Torres Strait and identified as good indicator organisms. Seasonal data for *T. maxima* are available from Campbell Island only. These show a very similar pattern to *T. crocea*, with elevated concentrations of cobalt, chromium, copper, iron and manganese following the monsoon season. Cadmium and zinc were also elevated, but the differences were not statistically significant. The concentration of renal selenium in *T. maxima* decreased over the monsoon period. The concentrations of copper and zinc were both significantly higher at Campbell Island than Aureed Island following the monsoon period, while marked increases in cadmium, cobalt, chromium and nickel were also evident. The same seasonal differences are not evident in the seagrass *T. hemprichii* from Campbell Island. Metal concentrations in the leaf of this species are also believed to reflect dissolved concentrations in the water, however metal uptake is completely passive. This suggests that the observed seasonal increases in trace metal concentrations in *T. crocea* and *T. maxima* arise as a result of an active process of uptake and accumulation.

Seasonal variation in trace metal concentrations in *P. margaritifera*, *T. niloticus* and *L. carponotatus* from Aureed Island is also generally consistent with that of *T. crocea* from the same location. All four species displayed increases in the concentrations of most trace metals during the pre-monsoon period. In contrast to *T. crocea* at Kokope Reef, the sea cucumber *S. chloronatus* showed little seasonal variation in trace metal concentrations at the same location. However, this is consistent with the limited seasonal variation in trace metal concentrations in sediments that were observed and an understanding that trace metal concentrations in the tissue of *S. chloronatus* reflect concentrations in the sediment.

Concentrations of aluminium, cadmium, cobalt, copper, mercury, manganese, lead and zinc in most biota (*T. hemprichii*, *T. crocea*, *T. maxima*, *P. margaritifera*, and *T. niloticus*) were highest, particularly during the post-monsoon season, at the more northern locations which are closest to the Papua New Guinea coast and Fly River. Only *L. carponotatus* displayed some inconsistency in this pattern. This is thought possibly to reflect the different source of trace metals in this carnivorous fish, which is believed to be almost exclusively via food in contrast to dissolved ions (*T. hemprichii*, *T. crocea*, *T. maxima*), particulates (*P. margaritifera*) and algae (*T. niloticus*). The elevated levels of aluminium, cobalt, copper, manganese, lead and zinc in biota from the most northern locations mirrors the concentrations of the same metals in sediments and is consistent with their primary source being the Fly River. Elevated levels of cadmium and mercury at the most northern locations are not reflected in high concentrations of the same metals in sediments.

The elevated levels of cadmium and mercury at the most northerly locations, which do not reflect concentrations in sediments and are not associated with the fine particulate component of terrestrial origin, are particularly interesting. Low salinities have been shown to increase the net uptake of cadmium in the mussel *Mytilus edulis* (Phillips, 1976) and both cadmium and mercury in the oyster *Saccostrea echinata* (Denton & Burdon-Jones, 1981). Clearly, this also provides the most parsimonious explanation for the elevation in cadmium concentration in the kidney of *T. crocea* at the most northern locations, but not at Aureed Island, during the post-monsoon season. High concentrations of cadmium in oysters have also been reported from Shark Bay in Western Australia and the Arnhem Land coast of Northern Territory where there are no anthropogenic sources of cadmium (e.g. McConchie et al., 1988; Peerzada & Dickinson, 1989). There is no evidence in the literature that low salinities also increase the net uptake of copper and zinc. However, a reduction in salinity is known to increase the dissolved concentrations of many trace metals, including copper, in coastal areas which are influenced by fresh water discharge from rivers (Balls, 1989). It is evident that laboratory studies which address the influence of salinity variation on the release of bio-available trace metals from sediments, and uptake and depuration of trace metals in *T. crocea* and *P. erosa* will be required before a clear understanding of the causes of seasonal fluctuations in at the most northerly locations can be understood.

Analyses of samples of *P. erosa* collected at Boigu and Saibai Islands identify statistically significant seasonal differences in the concentration of only two metals: copper and mercury. Both were elevated following the monsoon period. The sampling stations at which *P. erosa* were collected all lie along the PNG coast and are likely to be influenced to some degree by brackish water throughout the year. In contrast, the concentrations of most metals varied significantly among the different sampling locations within each sampling period. These differences are believed to reflect variation in bio-available concentrations of both particulate and dissolved metal forms.

Care should be taken in drawing conclusions from this particularly heterogeneous (on the basis of location and season) dataset. The relatively high concentrations of many metals from sampling locations on the PNG mainland (Fig. 57) suggests that there may be a strong off-shore gradient which could potentially be confounded with any long-shore gradient. Furthermore, the marked differences in concentrations of many metals, several being statistically significant, between the two mainland locations which are separated by only a few kilometres also suggest that inputs from rivers entering along the coast to the west of the Fly estuary may have a significant influence over local metal concentrations.

There were no significant differences among the coastal island locations in copper and zinc concentrations within the soft tissue of *P. erosa*. Both of these metals are identified above as being associated with coastal runoff, including Fly River discharge, from sediments and the kidney of *T. crocea*. On the basis of concentrations in *P. erosa*, the distribution of these two metals appears to be fairly even among the coastal island locations that were sampled. Cadmium concentrations, in contrast, were significantly higher in samples from Saibai Island when compared to Boigu Island, but not significantly different to samples from Parama Island. The concentrations of both zinc and cadmium in samples from island locations are higher away from the Fly River, while only copper is in relatively high concentrations at Parama Island which lies adjacent to the Fly estuary. These patterns are generally consistent with the distribution of cadmium, copper and zinc in sediments, which when normalized to allow for variation in particle size, showed no significant difference in concentrations along the coast from east to west (Zn) or were in highest concentrations at locations on the western side of the Torres Strait (Cd,Cu).

The high concentration of cadmium in some individuals of *P. erosa* from Saibai Village during the pre-monsoon sampling period is of particular interest. The concentrations of both cadmium and cobalt were significantly different between the Saibai Village and

Saibai Island sampling stations. However, while the concentration of cadmium was higher in samples from Saibai Village, cobalt concentrations were lower. The Saibai Island sampling station displayed the highest concentrations of cadmium among all five locations during the post-monsoon sampling period. These results confirm that the elevated cadmium concentrations in samples from Saibai Village may be a consequence of local influences, but that there nevertheless does appear to be some regional elevation in cadmium levels around Saibai Island. As cadmium has widespread use in electroplating, pigment, batteries and alloys, in contrast to cobalt which does not, contamination from metal waste (including car bodies) which has been left to deteriorate near the Saibai Village sampling station is a likely explanation for the spike in cadmium concentrations.

Regional Variation in Trace Metal Concentrations

The concentrations of cadmium, copper and zinc in sediments from station S1, which lies within the Fly River delta, are comparable with those recorded in other studies of Fly River delta sediments (e.g. Harris et al., 1989; Schneider, 1990; Alongi et al., 1991; Baker, 1991). As grain size is one of the most important factors controlling the concentration of trace metals in sediments, it is very difficult to make direct and meaningful comparisons of trace metal concentrations without compensating for grain-size effects (Fowler, 1990; Loring, 1991). Comparison with the results of other studies is also complicated by regional variation in natural background concentrations and a lack of knowledge of anthropogenic inputs from industry and mining (Fowler, 1990). As information on grain size and the level of anthropogenic inputs is almost invariably absent from published data on trace metal concentrations in sediments, comparison of the present results with those published in the literature will be limited.

Cadmium in sediments from stations S2 and S3 (0.05-0.09 mg kg^{-1}), where concentrations were highest, are below what is considered 'normal' (0.2-5.0 mg kg^{-1}) for 'cleaner inshore areas' (GESAMP, 1985, p.12). Cadmium, copper and zinc concentrations from the Torres Strait all fall within the range of values that have been reported in unpolluted tropical delta and coastal sediments generally (e.g. DeNardi et al., 1989, reported in Currey & Benko, 1991; Everaarts, 1989; Brodie et al., 1990; Fowler, 1990; Din, 1992). In the tropics, the principal source of trace metals to coastal sediments is through weathering and hydraulic transport and, as a consequence, concentrations tend to be highest close to rivers where the fines are deposited (Bewers & Yeats, 1989; Loring, 1991). While copper and zinc concentration at station S1 nevertheless appear to be relatively high (e.g. Harris et al., 1989; Baker et al., 1990;

Baker, 1991), they are orders of magnitude lower than some industrialized areas (see Bryan, 1984 for a review). Results from the present study with respect to cadmium concentrations, in particular, do not support the assertion by Baker et al. (1990) that the Torres Strait is contaminated with cadmium as a consequence of mining activities in the Fly River catchment.

On the basis of the biological concentration factors published by Denton and Heitz (1991), the estimated dissolved concentrations of cadmium, copper and zinc at Kokope Reef are, respectively, 2.72, 0.18 and 0.71 mg l^{-1}. Only the estimated value for cadmium concentration is far in excess of background concentrations in seawater of 0.01-0.1 mg l^{-1} or concentrations from coastal regions subjected to large anthropogenic inputs, which may be 5 to 10 times higher still (GESAMP, 1985; Denton and Burdon-Jones, 1986). The estimated value of 2.72 mg l^{-1} is probably an order of magnitude too high on the basis of Denton and Heitz's (1991) comparison of observed and predicted values for cadmium in seawater. It may also be excessive on the basis that the rate of uptake may have been increased as a consequence of lowered salinities, particularly during the monsoon period. It is not clear whether or not dissolved cadmium concentrations are high in the vicinity of Kokope Reef or the high concentration in biota is simply a reflection of the uptake kinetics of this metal. Nevertheless, cadmium concentration in the kidney of *T. crocea* from Kokope Reef does represent an increase in bio-availability when compared to samples from other locations within the GBR (Table 4), which are typically close to an order of magnitude lower.

The estimated dissolved concentration of zinc (0.71 mg l^{-1}) is twice the maximum measured in surface waters from the GBR (0.03-0.35 mg l^{-1}; Denton and Burdon-Jones, 1986), while concentrations in the kidney of *T. crocea* from Kokope Reef fall within the range of values found in samples from Orpheus Island in the GBR (Table 4). The estimated dissolved concentration of copper (0.18 mg l^{-1}) is similar to that measured in surface waters from Orpheus Island (0.16-0.23 mg l^{-1}; Denton and Burdon-Jones, 1986), while concentrations in the kidney of *T. crocea* from Kokope Reef are only slightly higher than concentrations found in samples from Orpheus Island (Table 4). However, renal copper has a biological half-life as low as two weeks in *T. crocea* (Denton and Heitz, 1991). The measured and estimated concentrations of copper are, therefore, unlikely to reflect the maximum environmental concentrations on the basis that samples were collected several weeks after the anticipated end of the north-westerly monsoon period when the brackish water intrusion into the Torres Strait is understood to be at its peak. In contrast, the biological half-life of renal cadmium and zinc is approximately six months in *T. crocea* (Denton and Heitz, 1991). On the other hand, the estimates of all dissolved metal concentrations in the environment based on biological concentration factors may be underestimated due to the inability of the biomonitor to attain equilibrium under conditions where there are episodic inputs of elevated trace metals (Denton & Heitz, 1991).

Sampling Strategies

The numbers of replicate samples that should be collected per site is conventionally estimated by cost-benefit equations (Underwood, 1981; Bernstein & Zalinski, 1983; Andrews & Mapstone, 1988). These equations estimate the optimum number of replicates by comparing costs to collect a single replicate, costs to sample an entire site, and measures of variance amongst sites and replicates. The TSBS costs per replicate for *T. crocea* include the cost to collect and process each sample, and the cost of chemical analysis, giving a total of approximately $166 per replicate. Costs per site include the time spent travelling from the mother ship to the sites and the time spent travelling between sites, coming to approximately $37 per *T. crocea* site. Values for variance among sites and replicates are derived from Analysis of Variance for each metal. Cost per replicate is always high and, as it is the denominator in the equation, it invariably leads to optimum numbers of replicates per site of less than, or close to, one. This procedure is clearly inappropriate for the TSBS sampling program. As five replicates per site provided the basis for the present calculations and estimates of variance, this number of replicates should be maintained for the present. Following the main study it would be appropriate to compare estimates of power and concentration change based on fewer replicates.

On the basis of the estimates of variance in metal concentrations derived from the pilot study data, it is apparent that the number of sites from which samples are collected should be maximized. Records of the time taken to collect and process *T. crocea*, and their distribution on reefs during the pilot study indicate that the maximum number of sites from which two teams of three persons could collect and process samples in one day is eight. In the case of *T. maxima* it would be difficult to collect from more than three sites as this species is relatively uncommon on the reef compared with *T. crocea*. Additional sites would also run the risk of overlapping, thus making invalid the statistical analyses for which collection has been designed. The distribution and abundance of *P. erosa* make three sites the maximum number from which samples can practicably be collected for this species.

In the case of sediments, there is some concern that the present size of the sampling station (200m x 200m) is already too small to ensure that there is no overlap in the sampling sites, thus making invalid the statistical analyses (nested ANOVA). Over the period of time that is required to collect three replicate grab samples there can be substantial movement in the position of the ship due to changes in the tide, windage and anchor drag. Yet, it is evident that the size/area of each sampling station should be kept as small as possible in order that differences in metal concentrations among sites within a station be minimized.

Any decision to limit the number of sites, for example, due to financial considerations, will have serious implications for the detection of differences in metal concentrations among locations. It is evident (Tables 10 and 11) that when power is maintained around 0.8, the percentage change that is able to be detected increases with a decreasing numbers of sites. If the number of sites from which samples of *T. crocea* could be collected was dropped from eight to four, the detectable increase in the range of copper concentrations above those detected during the pilot study would rise from 75% to more than 225% (Table 10).

Community Fishery

The NHMRC MPCs of metals in foods with which community fishery data are compared were developed by government agencies in an attempt to protect public health by exercising control over the metal content of foods (Rayment, 1991). Rayment (1991) notes that the established values are derived from toxicological studies on animals and broadly-based surveys of environmental concentrations for the purpose of regulation. However, MPCs are also strongly influenced by trade considerations (F. Stenhouse, pers. comm.). Exceedance of the MPC does not imply that the food item is unfit to eat and will necessarily result in illness. Exceedance of the MPC should serve as a guideline and, possibly, warning. The concentrations of metals in foods in excess of half the MPC are considered to warrant identification and monitoring (NHMRC, 1991). The appropriate method of assessing the risk of trace metal levels to human health is by considering the total metal intake from foods which constitute a significant part of the normal diet. The WHO/FAO recommend 'acceptable daily intake' and 'provisional tolerable weekly intake' levels of most metals.

Trace metal concentrations in the edible tissue of fishes were found to be at acceptable levels (i.e. below the MPC) in all but two species - the Murray Island sardine *Harengula ovalis* and the sardine/hardyhead. This finding should not be surprising as fish are known to have an ability to regulate the concentrations of metals (except mercury) in their muscle tissue. The concentration of cadmium in all individuals of *Harengula ovalis* is above the MPC, while the concentration of cadmium in two individuals of the sardine/hardyhead is above the MPC. Similarly, the concentration of selenium within two individuals of *Harengula ovalis* is above the MPC, while the concentration of arsenic appears to be close to the MPC. The main contributing factor to the elevated metal levels in *Harengula ovalis* and the sardine/hardyhead when compared to the MPC is most probably the contribution of the visceral mass to the total metal concentration. Only the muscle of other fish species was analysed for trace metal concentrations. Assessing the significance of arsenic concentrations is made difficult as the concentration of inorganic arsenic, on which the MPC is based, is unknown and can only be roughly estimated from the total arsenic concentration. However, there is a suggestion in the data that arsenic concentrations may be relatively high in several species of fish. The small sample size of most species precludes any other generalizations.

Samples of the sardine/hardyhead and the golden lined spinefoot *S. guttatus* from Darnley Island were prepared from recently dead individuals which were found along the shoreline. These were collected and analysed because of concern by Islanders that the cause of death may have resulted from trace metal contamination. The concentrations of all trace metals within the tissues examined fall within the range of concentrations found for the same species in live individuals from other locations. There is no evidence, therefore, that the cause of death was due to heavy metal overload. However, a more thorough investigation of the cause of such deaths would require that the liver concentrations of dead and live specimens be compared.

Most trace metal concentrations in the edible tissue of the molluscs that were collected were found to be at acceptable levels. The only metals which appear to be relatively high are arsenic and cadmium in the clam *H. hippopus* and red-lipped stromb *S. luhuanus*, and selenium in *H. hippopus*.

Trace metal concentrations in the edible tissue (tail muscle) of both species of crayfish, with the exception of arsenic, were found to be at acceptable levels. While the exact concentrations of inorganic arsenic are not known, the very high values for total arsenic suggest that the MPC is likely to be greatly exceeded. The concentrations of copper and selenium in some individuals were relatively high and approaching the MPC. The commercial fisheries component of the Torres Strait Baseline Study (Dight, 1991), which is specifically targeting trace metal concentrations in prawns and crayfish, is expected to report in June 1993.

The concentration of cadmium in the edible offal of turtle and dugong is well in excess of the MPC. Other metal concentrations which are above the MPC are mercury and selenium in the kidney and mercury and copper in the liver of dugong. All other trace metals are generally in concentrations well below the MPC. The concentrations of cadmium, copper and mercury within the kidney and liver of dugong fall within the range of values that has been recorded in dugong from the central GBR (Denton & Breck, 1981; Denton et al., 1980).

SUMMARY AND CONCLUSIONS

The Fly River is evidently a major source of fine-grained sediment containing a suite of trace metals including aluminium, cobalt, chromium, copper, iron, manganese, nickel, lead, silica and zinc to the northern Torres Strait. The fine-grained sediment of terrigenous origin is largely limited to the coastal region adjacent to Papua New Guinea. Arsenic, cadmium, magnesium, mercury and selenium are not primarily associated with terrigenous sediments and their concentrations in sediments are unlikely to have been significantly influenced by Fly River discharge. Cadmium is primarily associated with coarse-grained carbonates of marine origin.

Aluminium is identified as a geochemical normalizer for copper, iron, magnesium, manganese, nickel, lead, silica and zinc concentrations where there are differences among locations in the grain-size composition of sediments. On the basis of <200 μm and Al-normalized trace metal concentrations in sediments, it would appear that there is a major source of trace metals on the western side of the Torres Strait, possibly in Irian Jaya, or along the west coast of Cape York peninsula.

Data from the present study on metal concentrations in four species of bivalve mollusc (*T. crocea*, *T. maxima*, *P. margaritifera* and *P. erosa*), one gastropod mollusc (*T. niloticus*) and one fish (*L. carponotatus*) indicate that all are good indicator species of variation in trace metal bio-availability on the basis that they do not appear to regulate the concentrations of most metals in their tissues. They are all sessile, thus being representative of a location, easy to identify and sample, accumulate the trace metals of interest, provide sufficient tissue for analysis and are suitable for laboratory studies of pollutant kinetics. Both *T. crocea* and *P. erosa* are abundant throughout their habitats, despite some limitation to the distribution of their habitats within the Torres Strait. However, *T. maxima*, *P. margaritifera* and *T. niloticus* were found to have low abundance and a rather patchy distribution. On this basis, these three species are not recommended for future use as bio-monitors. *L. carponotatus* is not recommended because of logistic difficulties in sampling this species and some apparent inconsistencies with the other bio-monitors which cannot be adequately explained. Importantly, Denton and Heitz (1991) have shown that a relationship exists between the pollutant concentration found in the tissues of *T. crocea* and the average ambient pollutant concentration.

Increases in the concentrations of four metals, cadmium, copper, strontium and zinc, appear to be associated with coastal runoff during the monsoon period. This finding is based on an understanding that: (a) intrusion of brackish water into the northern Torres Strait is greatest during the monsoon season; and (b) increases in the concentrations of cadmium, copper, strontium and zinc at the northern-most locations correspond to the same period. Changes in the levels of these metals may result from: (1) increased concentrations associated with river discharge; and/or (2) physico-chemical changes in the watermass leading to increases in (a) the bio-available portion of these metals only and/or (b) metal kinetics within biota. With respect to cadmium, the latter explanation - physico-chemical changes in the watermass - is most likely. Changes in the concentrations of aluminium, arsenic, cobalt, mercury, nickel, lead, selenium and uranium over the monsoon period are thought to be unrelated to coastal runoff.

Results based on trace metal concentrations in the kidney of *T. crocea* and *T. maxima* indicate that most dissolved metal concentrations (copper, mercury, nickel, lead and zinc in particular) in the central Torres Strait during the pre- and post-monsoon seasons are not elevated above concentrations found elsewhere within the GBR. Only cadmium concentration appears to be substantially higher in the Torres Strait than elsewhere within the GBR, while copper may be elevated following the monsoon season at the most northerly sampling location (Kokope Reef) only. On the basis of concentrations in most of the biota that were collected and analysed, both dissolved and particulate metals appear to be locally elevated in the northern Torres Strait.

Samples of *P. erosa* collected from Boigu and Saibai Islands identify seasonal differences in the concentration of only two metals, copper and mercury, both of which were elevated following the monsoon period. Only copper concentrations were elevated in a manner which is consistent with its origin in discharge entering the northern Torres Strait from the Fly River during the monsoon period. The marked differences in concentrations of many metals between the two mainland locations, which are separated by only a few kilometres, suggest that inputs from rivers entering along the coast to the west of the Fly estuary may have a significant influence over local metal concentrations.

The concentrations of arsenic, cadmium, copper, zinc and selenium in the edible portion (particularly liver and kidney tissues) of some foods consumed by Torres Strait Islanders repeatedly appear at levels close to or above the NHMRC MPCs for seafoods. Many of these foods (e.g. the Murray Island sardine *Harengula ovalis*, the sardine/hardyhead, the green turtle *C. mydas* and the dugong *D. dugon*) are reported to be important components of the diet of many Torres Strait Islanders (V. McGrath, pers. comm.). While this should not be taken to signify an immediate health threat, it does indicate the need for a more detailed study of the diet of Torres Strait Islanders and the metal concentrations associated with the foods that are consumed. The metals arsenic, cadmium and selenium are not believed to be associated with Fly River discharge to any appreciable degree but copper may be. Similar high levels of these metals have been found in dugong liver and kidney tissues from other parts of the Great Barrier Reef in previous studies (Denton et al., 1980).

Recommendations

It is recommended that:

(1) The arrangement and number of sampling stations should be modified from that originally proposed and be as indicated in Figures 93 and 94 for sediments and biota respectively. The western leg of the sediment transect which parallels the PNG coast should be moved closer inshore (see Fig. 93) so that variation in grain-size among locations is minimized. The station size for sediment sampling should be increased to 500m x 500m to avoid pseudo-replication of sites;

(2) Sampling of both sediments and biota as indicator organisms for the main study should be carried out during two periods: the pre-monsoon (October-November) and monsoon (February-March) seasons;

(3) The boring clam *Tridacna crocea* and the mangrove cockle *Polymesoda erosa* should be selected as indicator species for the main study. The shell length of *T. crocea* should be restricted to a size range of 70 to 80 mm. An alternative to shell length should be investigated as a measure of age (e.g. growth rings and shell weight);

(4) *T. crocea* should be collected along three transects from the following locations: Kokope Reef, Warrior Reef, Dungeness Reef, Poll Island, Campbell Island, Rennel Island, Aureed Island, Toms Son Bank, Bramble Cay, Underdown Reef, Little

Mary Reef and Hibernia Passage reef. Five replicate samples should be collected from each of eight sites per location. Both replicates and sites should be randomly selected;

(5) *P. erosa* should be collected along three transects from the following locations: Boigu Island, Saibai Island, Bobo Island, Kussa Island, Warukuik, West Aberemuba, Zaigai Island and Sassie Island. Five replicate samples should be collected from each of three sites per location. Both replicates and sites should be randomly selected. Specimens should be flushed with double de-ionized water to remove any sediment adhering to the surface of the soft tissue or within the gut.

(6) The community fishery collection programme should continue. As a result of the paucity of samples from some locations, the small sample sizes and the relatively high concentrations of some metals in many species, collection should place an emphasis on:

(a) locations where few samples have been collected to date (e.g. Boigu and Saibai Islands); and

(b) those species which show relatively high concentrations of metals (e.g. *Agrioposphyraena barracuda*, *Choerodon schoenleinii*, *Epinephelus fasciatus*, *Harengula ovalis*, the sardine/hardyhead, *Chelonia mydas* and *Dugong dugon*);

(7) Consideration should be given to establishing a 'market basket' survey (of the type referred to in NHMRC, 1991) of the trace metal levels in the foods which constitute a significant part of the normal Torres Strait Islander diet. Representative communities from the different regions of the Torres Strait should be selected; and

(8) Future chemical analysis of samples should include tin (Sn) and establish the levels of inorganic arsenic. The concentrations of both of these metals are unknown at present, yet they are important in assessing the health implications of metals in diets. Consideration should be given to reanalysing samples from the present study which show high levels of total arsenic, for inorganic arsenic concentrations and tin, where sufficient material remains.

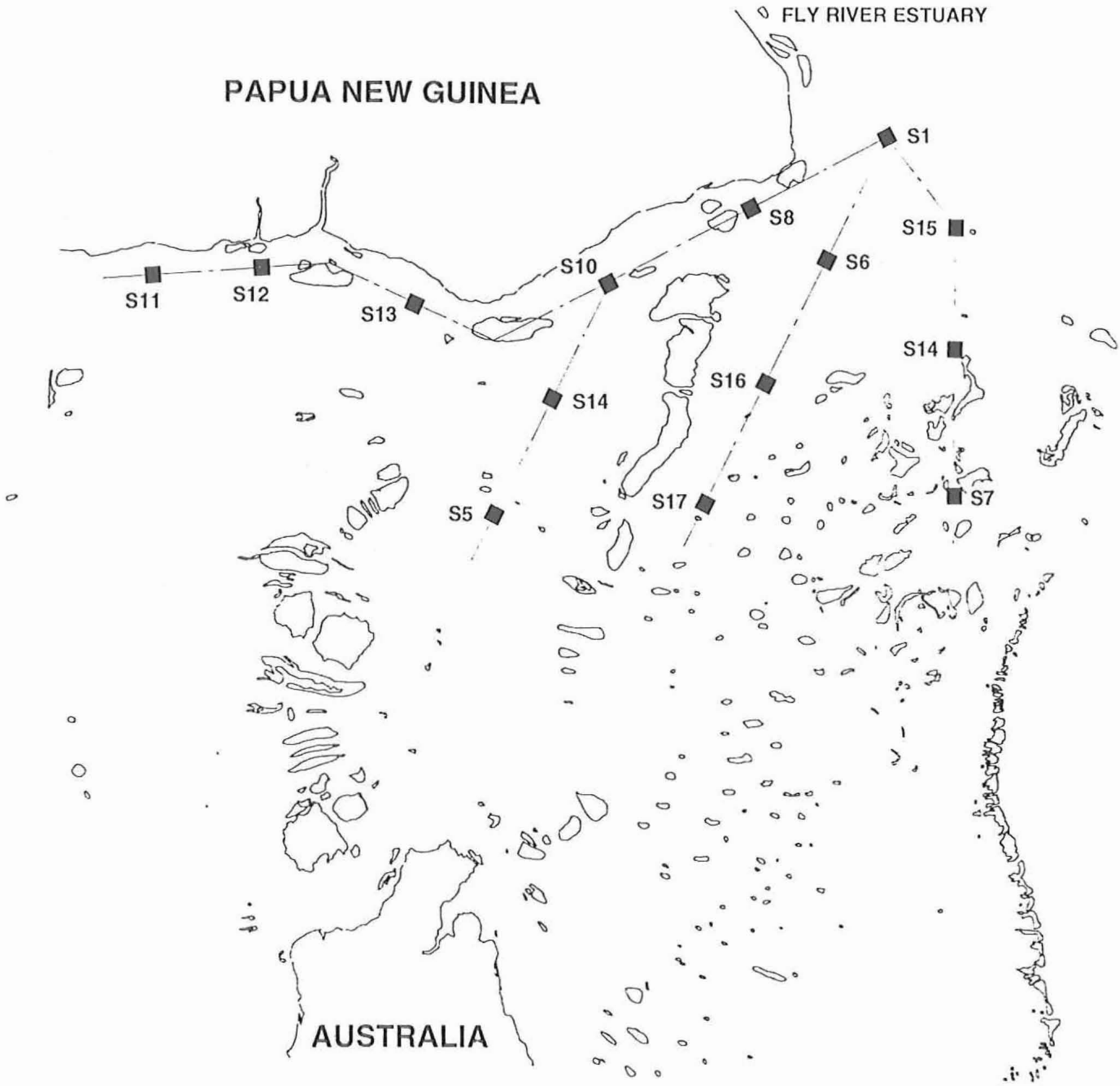

Figure 93. Map of the Torres Strait and northern Great Barrier Reef identifying the location and arrangement of sampling stations at which sediment should be collected for the main study.

Figure 94. Map of the Torres Strait and northern Great Barrier Reef identifying the location and arrangement of sampling stations at which indicator species should be collected for the main study.

ACKNOWLEDGEMENTS

The Torres Strait Baseline Study (TSBS) has been funded by a special allocation from the Australian Government and generous contributions from BHP Minerals and Porgera Joint Venture comprising Placer (PNG) Pty Limited, Highlands Gold Properties Pty Limited, Renison Goldfields Consolidated Limited and Mineral Resources Development Company Pty Limited and is being managed by the Great Barrier Reef Marine Park Authority. The development of the scientific programme has benefited from recommendations by the TSBS Advisory Committee. Data from Raine Island was kindly provided by the Raine Island Corporation through Mr G. Barry and Mr G. Rayment (QDPI).

Many people have contributed in a variety of ways to the data collection and analysis. These include (in alphabetical order) Ms Libby Evans-Illidge, Mr Peter Illidge, Dr David Lawrence, Mr Dennis Lee Sye, Dr Bruce Mapstone, Mr Vic McGrath, and Mr Ron Szymczak (ANSTO) and numerous field assistants. Mr Jim Vanderkamp (Horn Island Research Station) assisted in the use of the research station. The crews of the RV *Sunbird* (Lois Wilson and Terry Ford) and the MV *Western Venturer* were always helpful. The use of the MV *Western Venturer* was generously provided by OK Tedi Mining Ltd. Samples were prepared by staff from the Queensland Department of Primary Industries (QDPI) at the Horn Island Research Station and the labs in Brisbane, sometimes at no cost to the Baseline Study. In particular we wish to acknowledge the efforts of Mr Glen Barry, Dr Hugh Mawhinney, Mr Gerry Murphy and Mr George Rayment. Chemical analyses were carried out by QDPI (Animal Research Institute and Agricultural Chemistry Branch), Queensland Government Chemical Laboratory (GCL) and Australian Government Analytical Laboratory (AGAL). The TSBS Advisory Committee provided invaluable guidance and advice throughout the project.

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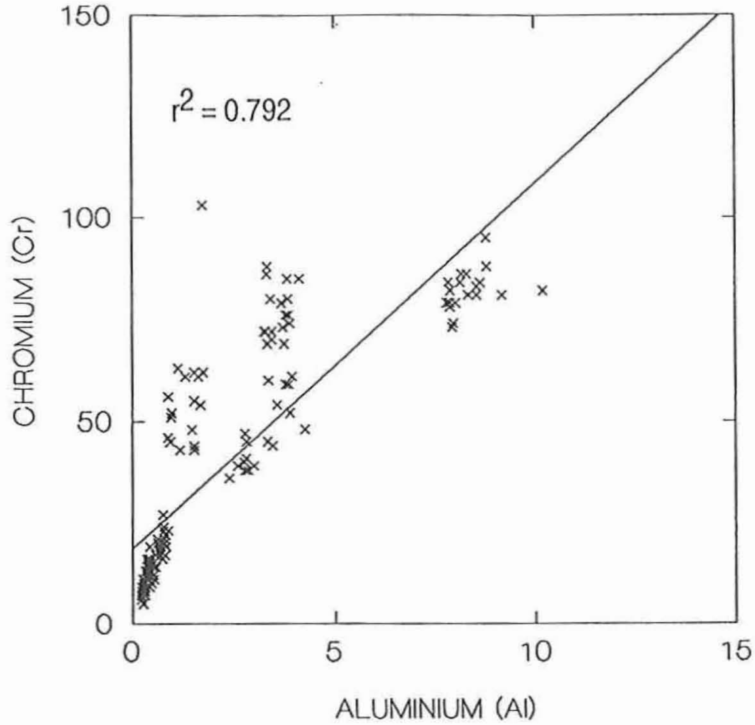
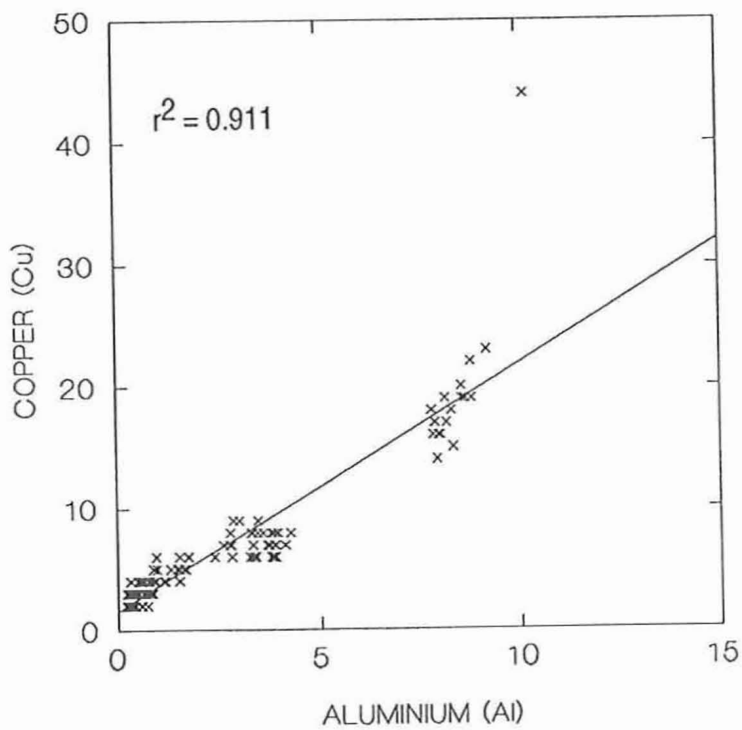
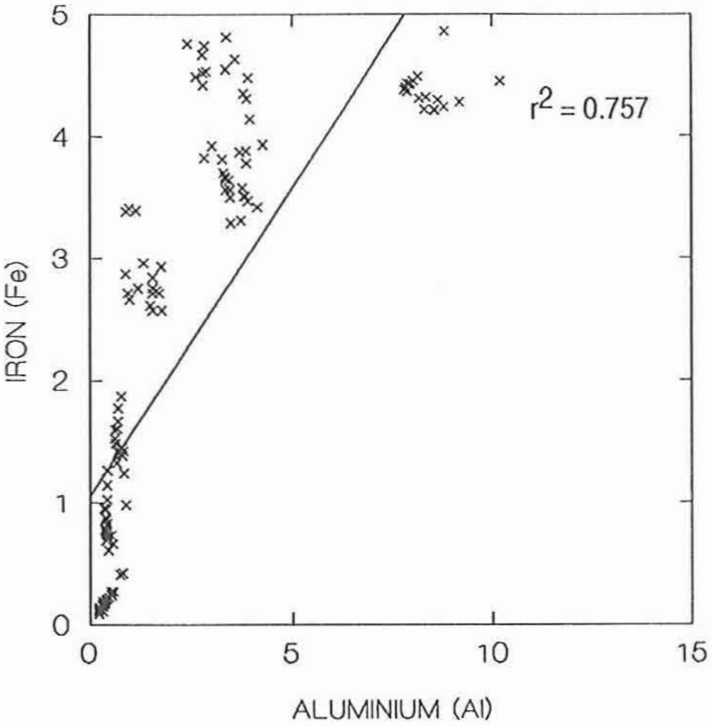
APPENDIX



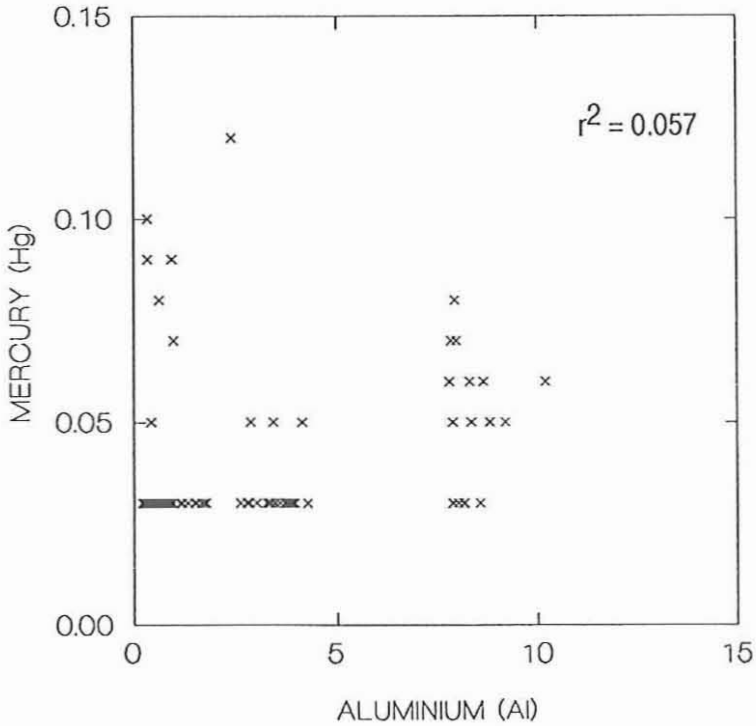
Appendix Figure 5. Relationship between aluminium and chromium concentrations in sediments (collected using a Smith-MacIntyre grab) from all sampling stations.



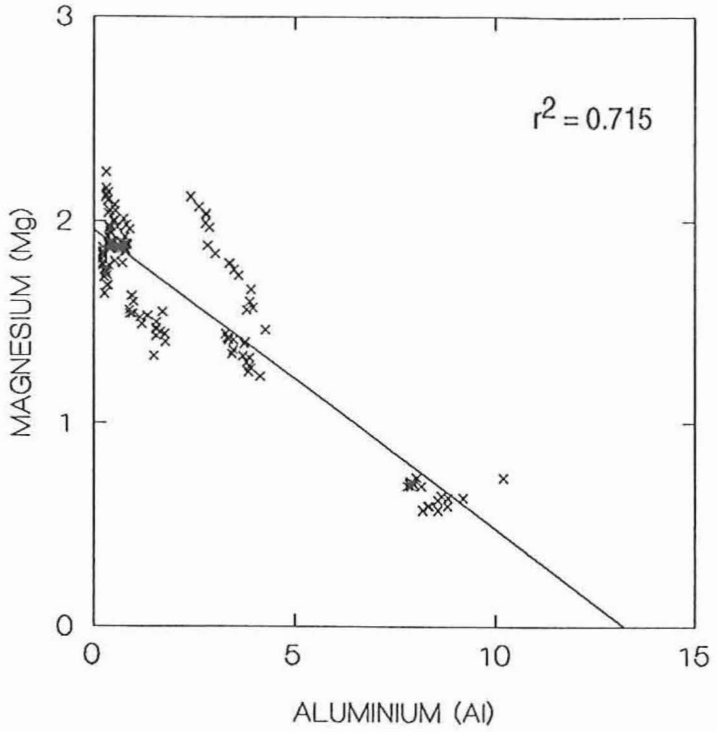
Appendix Figure 6. Relationship between aluminium and copper concentrations in sediments (collected using a Smith-MacIntyre grab) from all sampling stations.stations



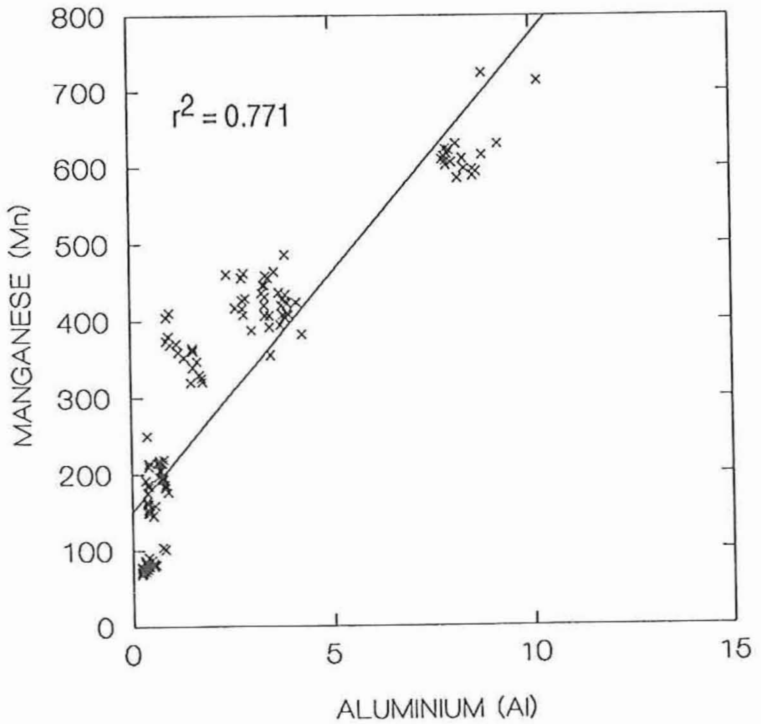
Appendix Figure 7. Relationship between aluminium and iron concentrations in sediments (collected using a Smith-MacIntyre grab) from all sampling stations.



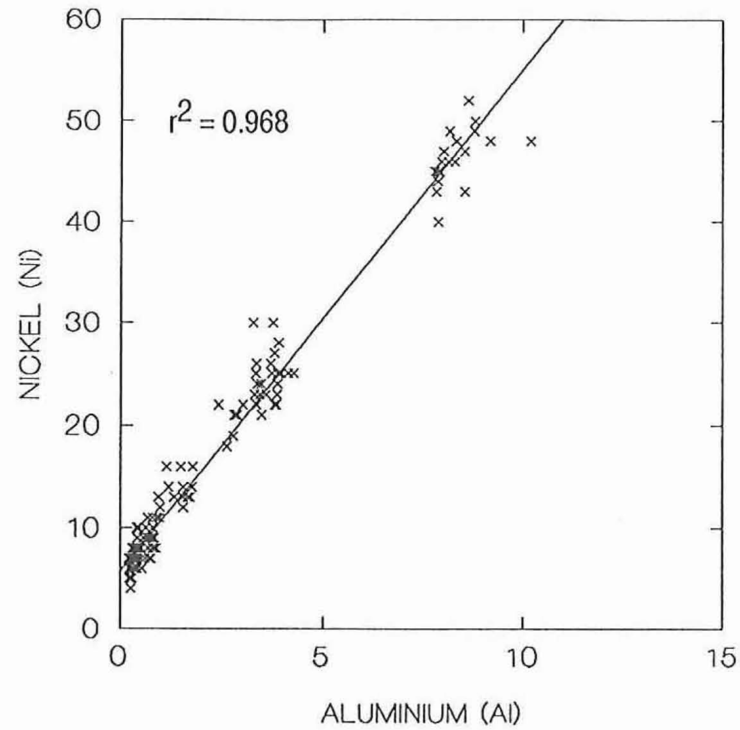
Appendix Figure 8. Relationship between aluminium and mercury concentrations in sediments (collected using a Smith-MacIntyre grab) from all sampling stations.



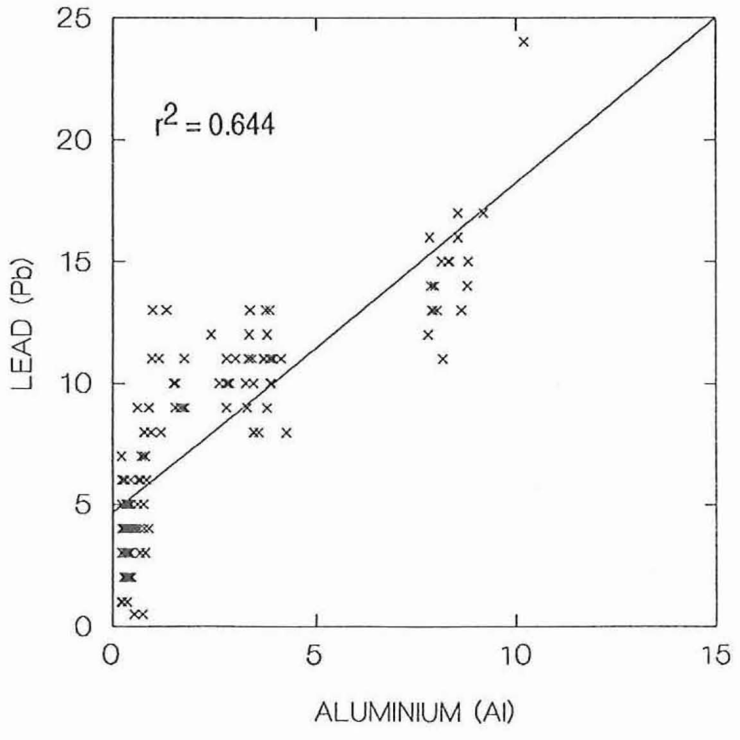
Appendix Figure 9. Relationship between aluminium and magnesium concentrations in sediments (collected using a Smith-MacIntyre grab) from all sampling stations.



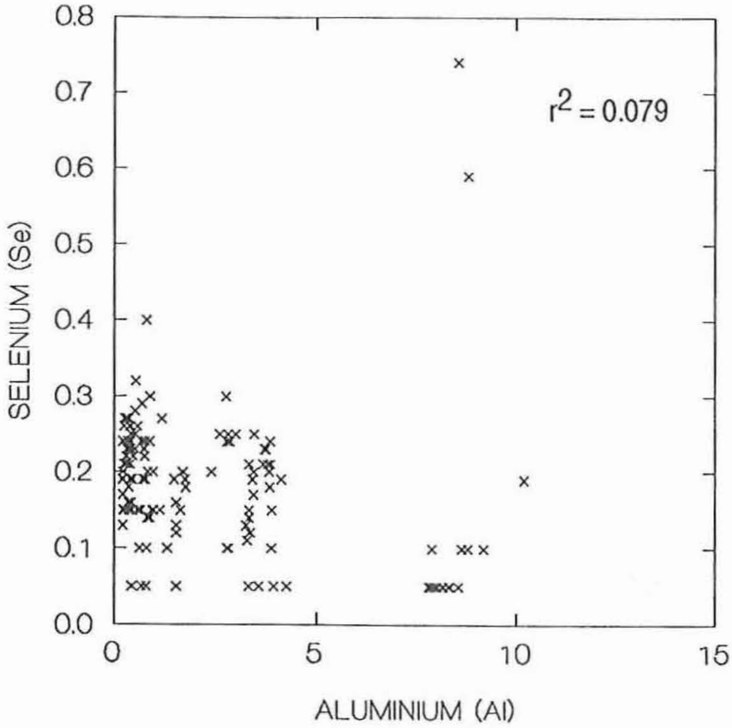
Appendix Figure 10. Relationship between aluminium and manganese concentrations in sediments (collected using a Smith-MacIntyre grab) from all sampling stations.



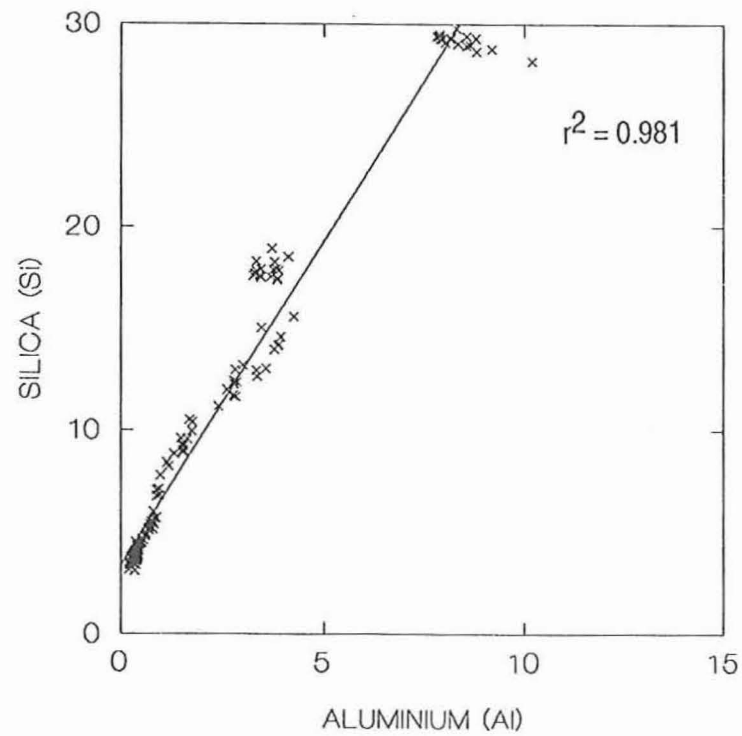
Appendix Figure 11. Relationship between aluminium and nickel concentrations in sediments (collected using a Smith-MacIntyre grab) from all sampling stations.



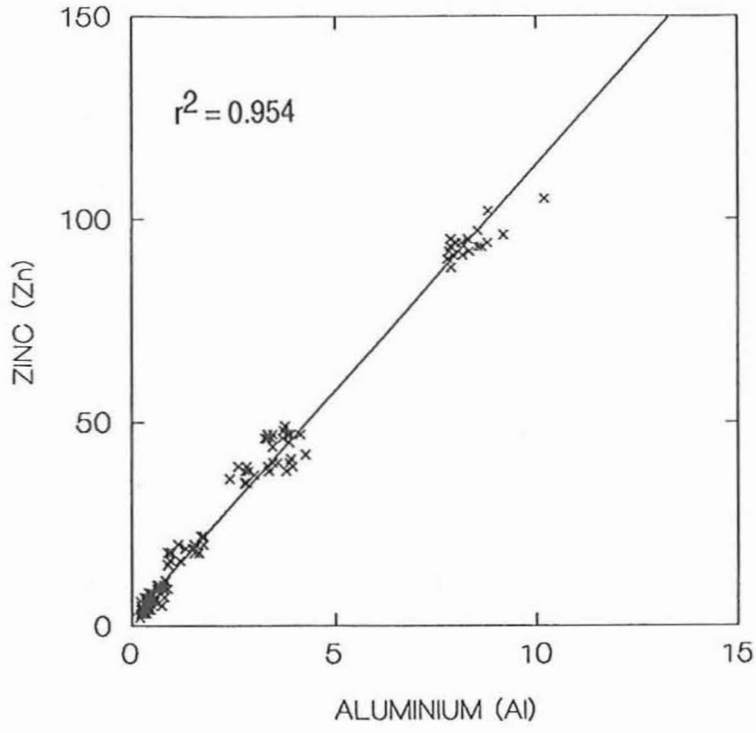
Appendix Figure 12. Relationship between aluminium and lead concentrations in sediments (collected using a Smith-MacIntyre grab) from all sampling stations.



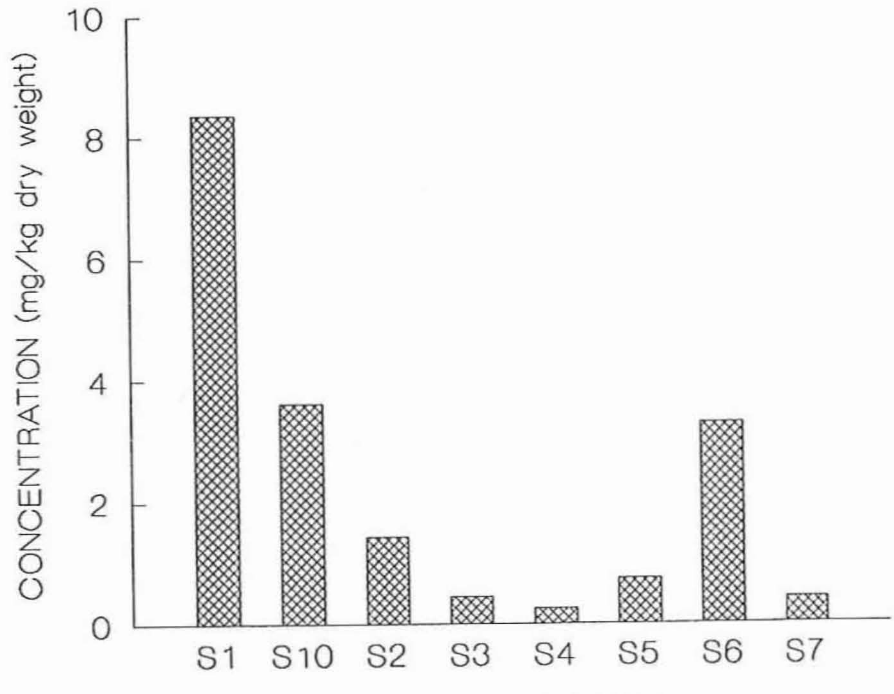
Appendix Figure 13. Relationship between aluminium and selenium concentrations in sediments (collected using a Smith-MacIntyre grab) from all sampling stations



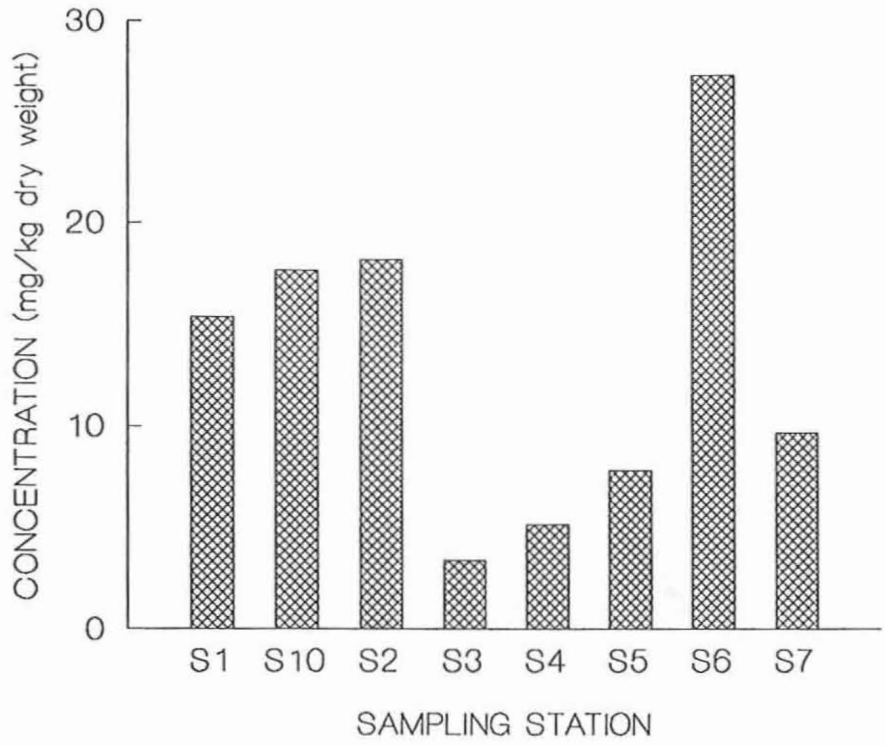
Appendix Figure 14 . Relationship between aluminium and silica concentrations in sediments (collected using a Smith-MacIntyre grab) from all sampling stations.



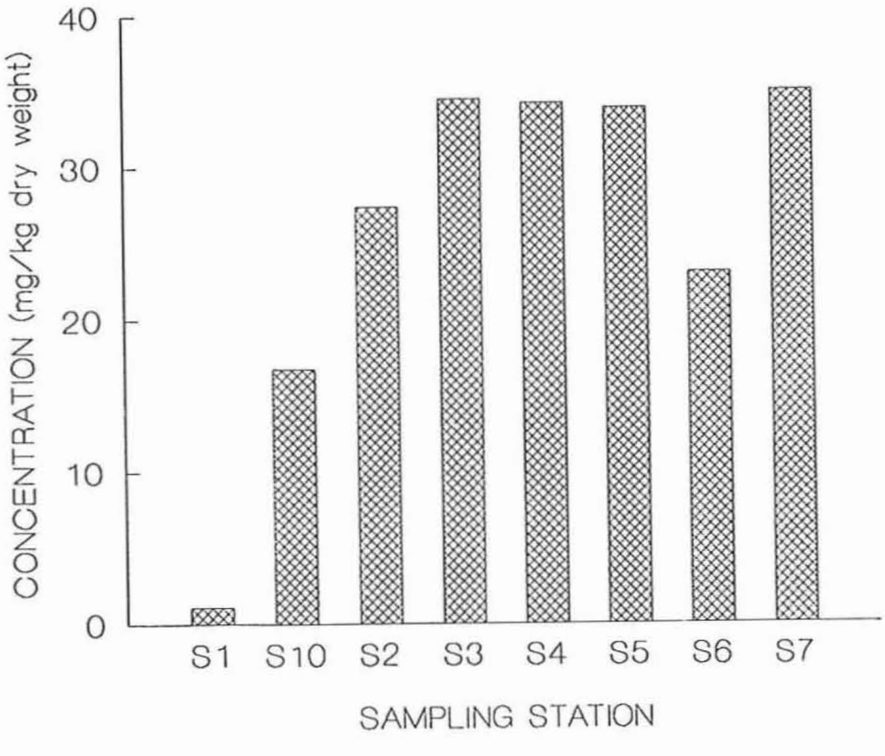
Appendix Figure 15. Relationship between aluminium and zinc concentrations in sediments (collected using a Smith-MacIntyre grab) from all sampling stations.



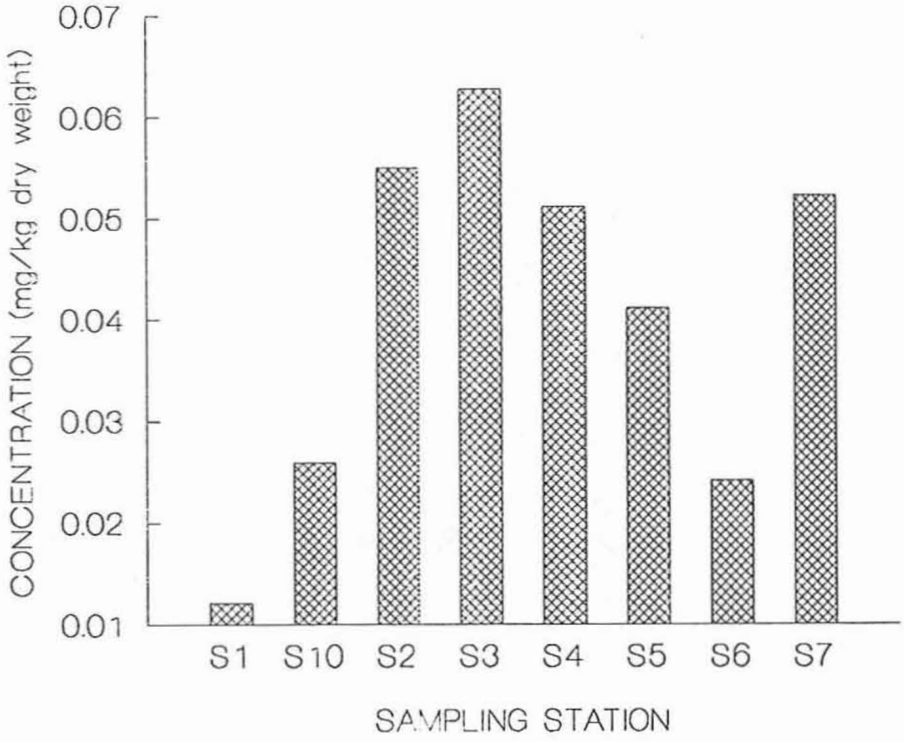
Appendix Figure 16. Aluminium (Al) concentration (averaged over two seasons) in sediments (collected using a Smith-MacIntyre grab) from all sampling stations.



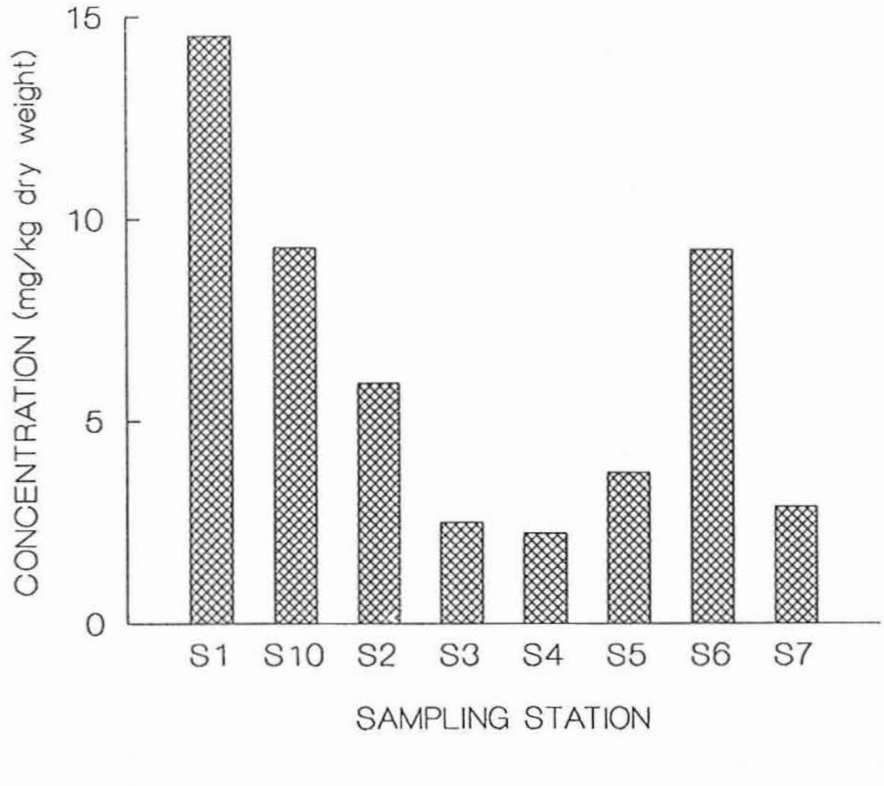
Appendix Figure 17. Arsenic (As) concentration (averaged over two seasons) in sediments (collected using a Smith-MacIntyre grab) from all sampling stations.



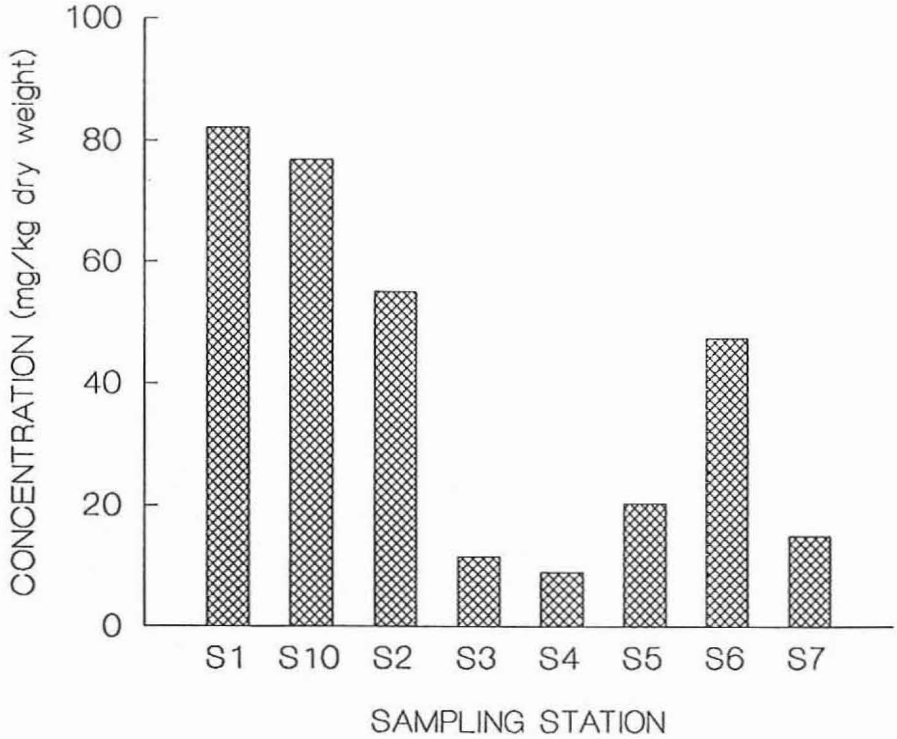
Appendix Figure 18. Calcium (Ca) concentration (averaged over two seasons) in sediments (collected using a Smith-MacIntyre grab) from all sampling stations.



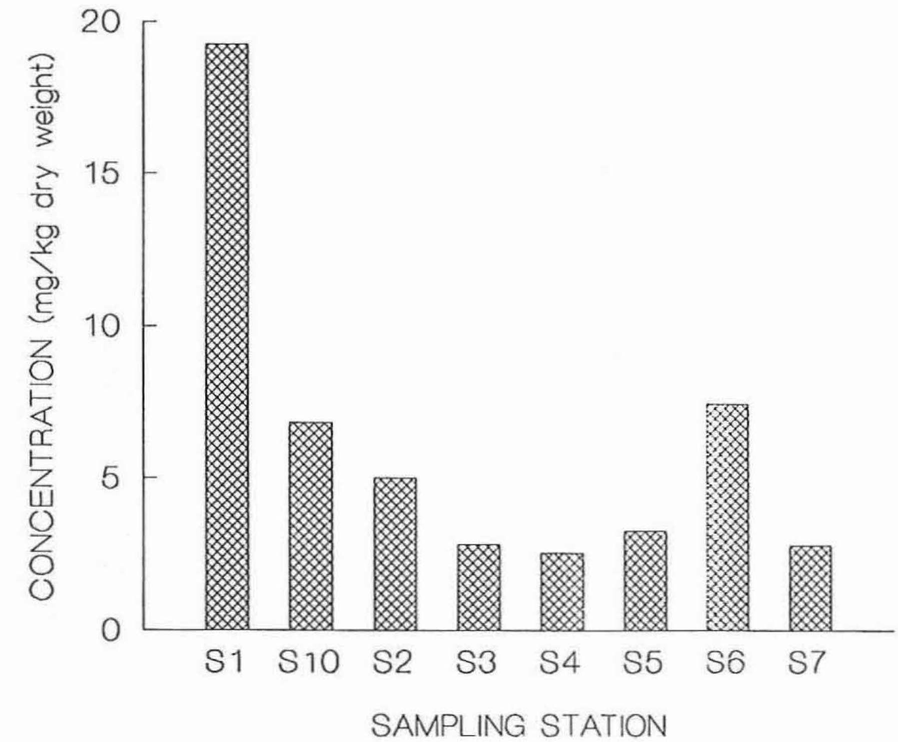
Appendix Figure 19. Cadmium (Cd) concentration (averaged over two seasons) in sediments (collected using a Smith-MacIntyre grab) from all sampling stations.



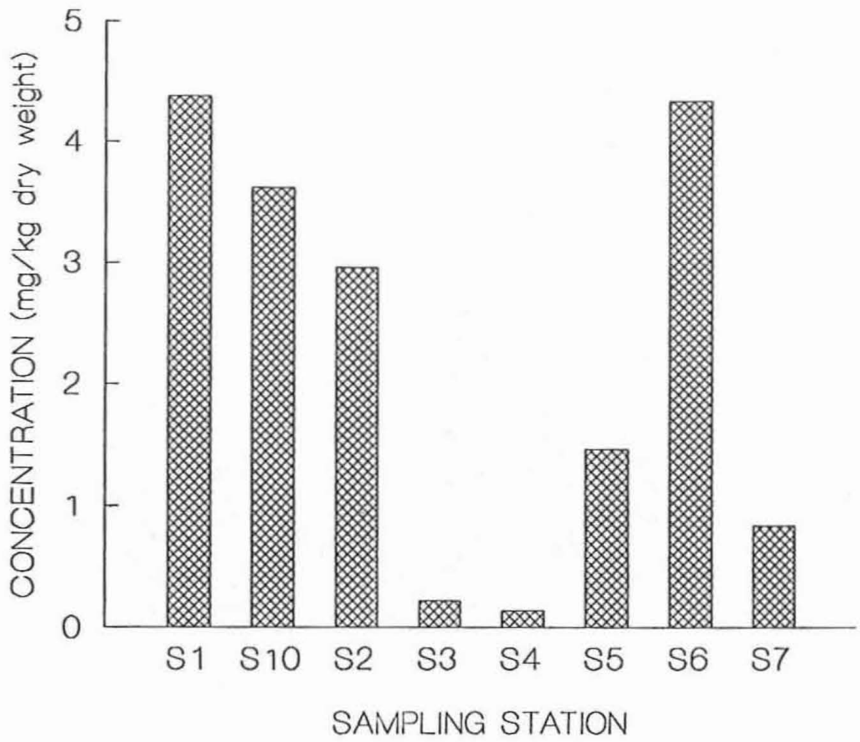
Appendix Figure 20. Cobalt (Co) concentration (averaged over two seasons) in sediments (collected using a Smith-MacIntyre grab) from all sampling stations.



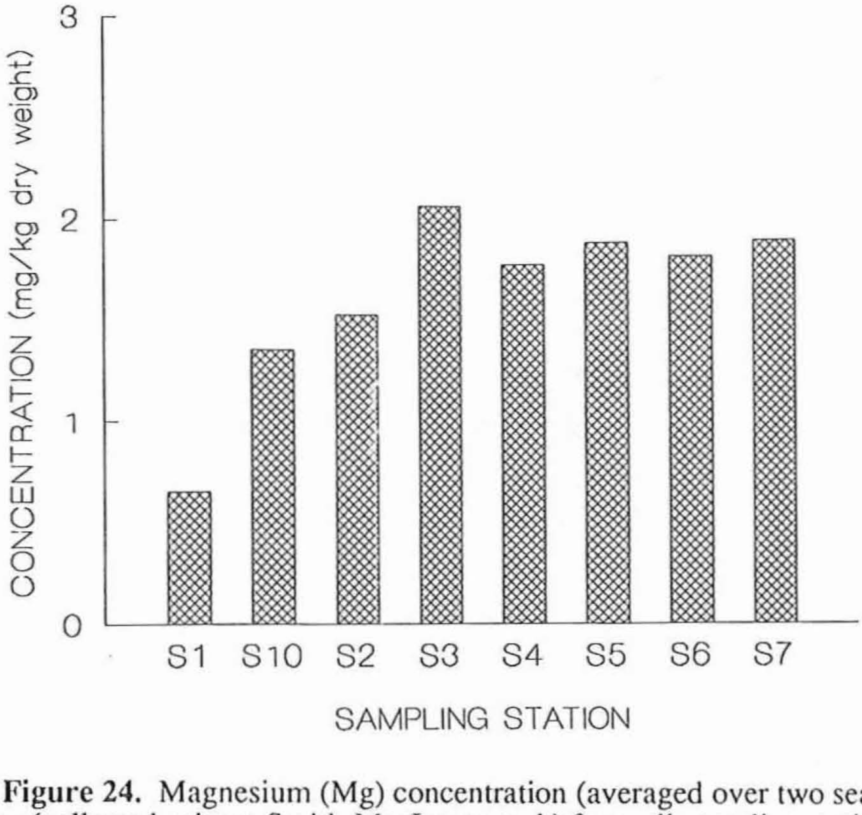
Appendix Figure 21. Chromium (Cr) concentration (averaged over two seasons) in sediments (collected using a Smith-MacIntyre grab) from all sampling stations.



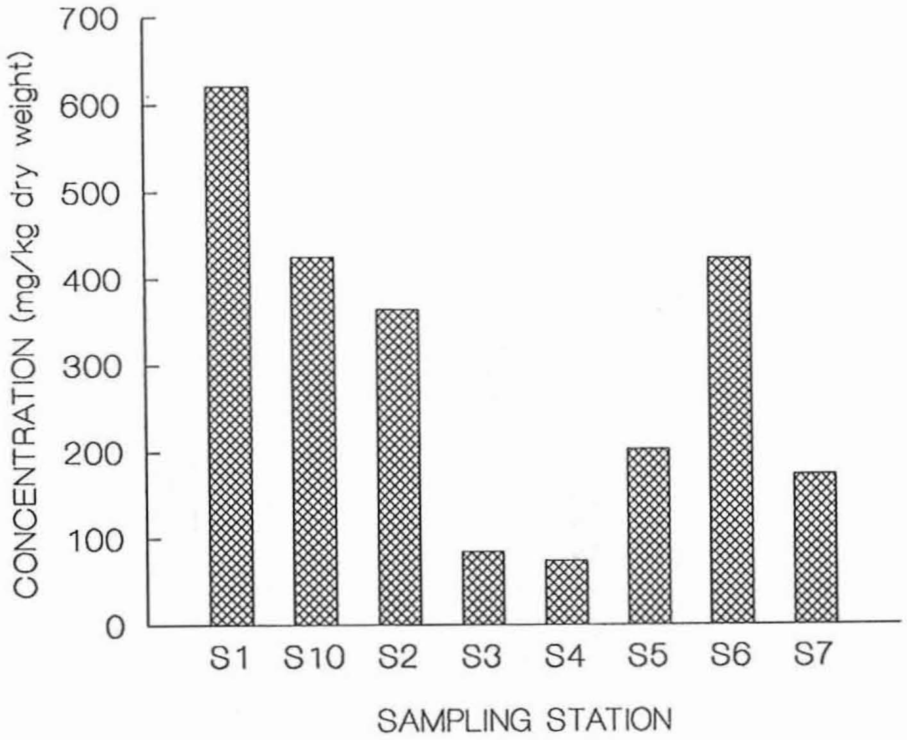
Appendix Figure 22. Copper (Cu) concentration (averaged over two seasons) in sediments (collected using a Smith-MacIntyre grab) from all sampling stations



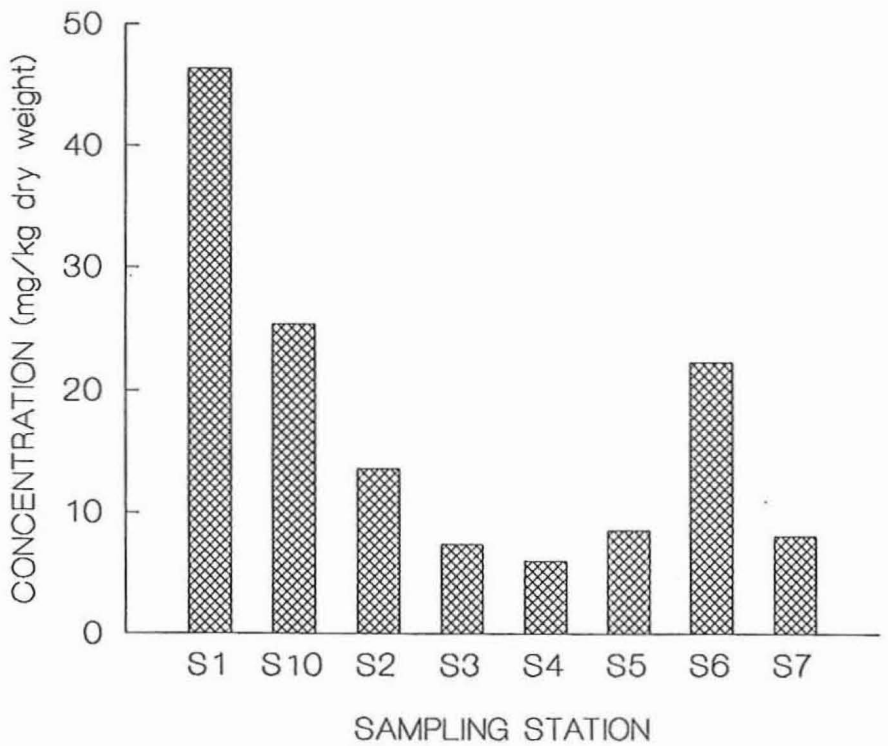
Appendix Figure 23. Iron (Fe) concentration (averaged over two seasons) in sediments (collected using a Smith-MacIntyre grab) from all sampling stations



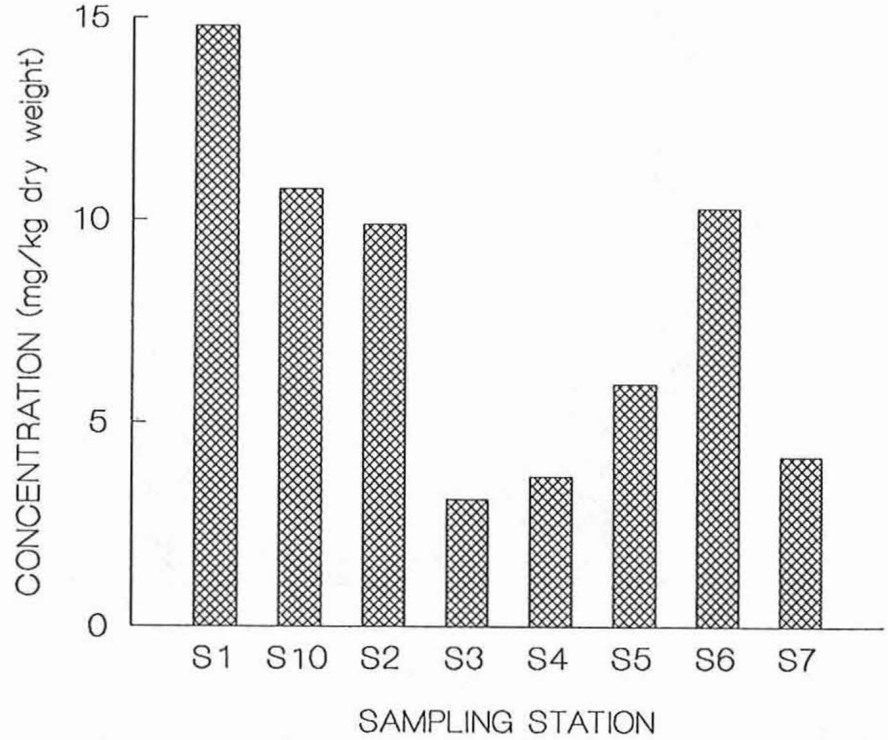
Appendix Figure 24. Magnesium (Mg) concentration (averaged over two seasons) in sediments (collected using a Smith-MacIntyre grab) from all sampling stations.



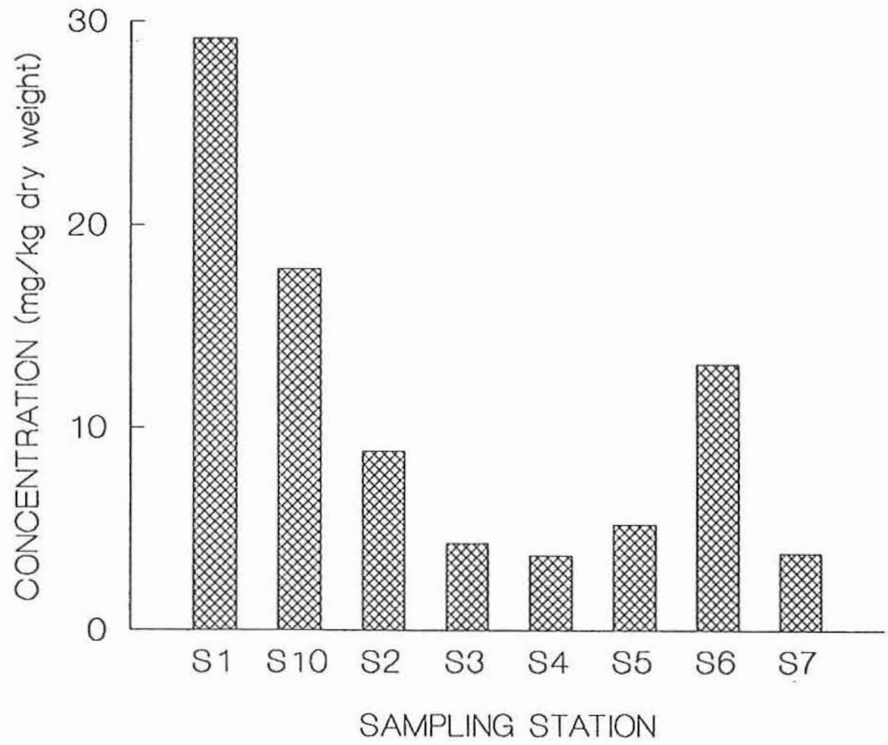
Appendix Figure 25. Manganese (Mn) concentration (averaged over two seasons) in sediments (collected using a Smith-MacIntyre grab) from all sampling stations.



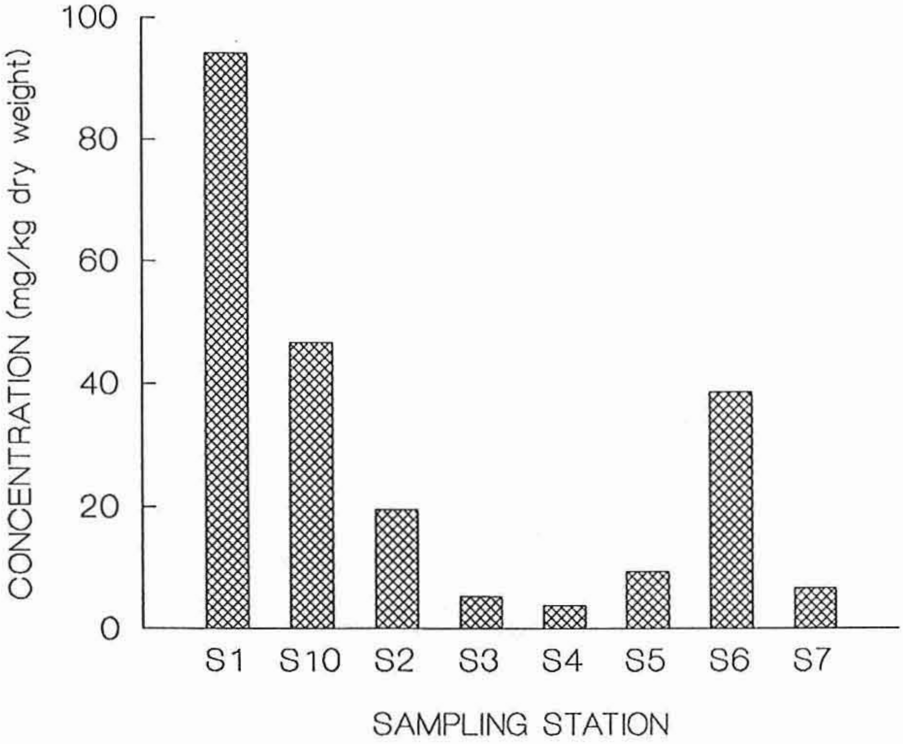
Appendix Figure 26. Nickel (Ni) concentration (averaged over two seasons) in sediments (collected using a Smith-MacIntyre grab) from all sampling stations



Appendix Figure 27. Lead (Pb) concentration (averaged over two seasons) in sediments (collected using a Smith-MacIntyre grab) from all sampling stations



Appendix Figure 28. Silica (Si) concentration (averaged over two seasons) in sediments (collected using a Smith-MacIntyre grab) from all sampling stations.



Appendix Figure 29. Zinc (Zn) concentration (averaged over two seasons) in sediments (collected using a Smith-MacIntyre grab) from all sampling stations.

Appendix Table 1. Analysis of Variance for differences in transformed metal concentration ($\log_e$(concentration+1)) in sediments from eight locations within two seasons.

Metal	Source of Variation	DF	MS	F-ration	Significance
Al	Season	1	0.063	2.182	p=0.149
	Station	7	9.336	321.923	p<0.001
	Season*Station	7	0.048	1.671	p=0.152
	Site{season* station}	32	0.029		
As	Season	1	0.014	0.060	p=0.808
	Station	7	7.053	29.633	p<0.001
	Season*Station	7	0.076	0.317	p=0.941
	Site{season* station}	32	0.238		
Cd	Season	1	0.001	0.552	p=0.463
	Station	7	0.005	6.967	p<0.001
	Season*Station	7	0.001	0.686	p=0.683
	Site{season* station}	32	0.001		
Co	Season	1	0.625	8.009	p=0.008
	Station	7	6.354	81.461	p<0.001
	Season*Station	7	0.086	1.101	p=0.386
	Site{season* station}	32	0.078		
Cr	Season	1	0.158	1.799	p=0.189
	Station	7	13.044	14.228	p<0.001
	Season*Station	7	0.068	0.768	p=0.618
	Site{season* station}	32	0.088		
Cu	Season	1	0.006	0.054	p=0.818
	Station	7	6.298	59.411	p<0.001
	Season*Station	7	0.033	0.315	p=0.942
	Site{season* station}	32	0.106		
Fe	Season	1	0.017	0.501	p=0.484
	Station	7	7.325	215.455	p<0.001
	Season*Station	7	0.017	0.488	p=0.836
	Site{season* station}	32	0.034		
Hg	Season	1	0.001	0.635	p=0.431
	Station	7	0.001	0.343	p=0.928
	Season*Station	7	0.000	0.096	p=0.998
	Site{season* station}	32	0.002		
Mg	Season	1	0.011	5.696	p=0.023
	Station	7	0.715	357.371	p<0.001
	Season*Station	7	0.012	5.841	p<0.001
	Site{season* station}	32	0.002		
Mn	Season	1	0.000	0.012	p=0.914
	Station	7	10.905	419.442	p<0.001
	Season*Station	7	0.012	0.455	p=0.859
	Site{season* station}	32	0.026		

(Appendix Table 1 continued over)

Metal	Source of Variation	DF	MS	F-ration	Significance
Ni	Season	1	0.003	0.080	p=0.779
	Station	7	8.338	203.363	p<0.001
	Season*Station	7	0.028	0.674	p=0.693
	Site{season* station}	32	0.041		
Pb	Season	1	0.762	2.575	p=0.118
	Station	7	4.993	16.870	p<0.001
	Season*Station	7	0.088	0.299	p=0.949
	Site{season* station}	32	0.296		
Se	Season	1	0.005	0.199	p=0.659
	Station	7	0.018	0.767	p=0.618
	Season*Station	7	0.020	0.850	p=0.555
	Site{season* station}	32	0.023		
Si	Season	1	0.111	5.563	p=0.025
	Station	7	8.918	445.915	p<0.001
	Season*Station	7	0.015	0.769	p=0.617
	Site{season* station}	32	0.020		
Zn	Season	1	0.020	0.376	p=0.544
	Station	7	21.147	391.602	p<0.001
	Season*Station	7	0.007	0.131	p=0.995
	Site{season* station}	32	0.054		

Appendix Table 2. Analysis of Variance for differences in transformed metal concentration ($\log_e$(concentration+1)) in sediments from Station S10 within two seasons using two sampling methods.

Metal	Source of variation	S	MS	F-ratio	Significance
A1	Season	1	0.115	38.880	p<0.001
	Method	1	0.000	0.067	p=0.802
	Season*Method	1	0.001	0.392	p=0.549
	Site{season* method}	8	0.003		
As	Season	1	0.003	0.019	p=0.894
	Method	1	0.000	0.001	p=0.979
	Season*Method	1	0.000	0.002	p=0.967
	Site{season* method}	8	0.132		
Cd	Season	1	0.000	1.463	p=0.239
	Method	1	0.000	9.209	p=0.006
	Season*Method	1	0.000	3.304	p=0.082
	Site{season* method}	8	0.000		
Co	Season	1	0.074	10.536	p=0.012
	Method	1	0.001	0.110	p=0.749
	Season*Method	1	0.006	0.881	p=0.375
	Site{season* method}	8	0.007		
Cr	Season	1	0.012	0.543	p=0.482
	Method	1	0.004	0.194	p=0.671
	Season*Method	1	0.005	0.220	p=0.652
	Site{season* method}	8	0.022		
Cu	Season	1	0.000	0.000	p=0.989
	Method	1	0.000	0.000	p=0.993
	Season*Method	1	0.005	0.051	p=0.826
	Site{season* method}	8	0.089		
Fe	Season	1	0.000	0.003	p=0.955
	Method	1	0.000	0.017	p=0.899
	Season*Method	1	0.001	0.066	p=0.804
	Site{season* method}	8	0.014		
Hg	Season	1	0.001	0.418	p=0.536
	Method	1	0.000	0.224	p=0.649
	Season*Method	1	0.001	0.418	p=0.536
	Site{season* method}	8	0.001		
Mg	Season	1	0.006	4.659	p=0.063
	Method	1	0.002	1.799	p=0.217
	Season*Method	1	0.002	1.745	p=0.223
	Site{season* method}	8	0.001		
Mn	Season	1	0.000	0.002	p=0.962
	Method	1	0.000	0.003	p=0.958
	Season*Method	1	0.000	0.021	p=0.889
	Site{season* method}	8	0.018		

(Appendix Table 2 continued over)

Metal	Source of variation	S	MS	F-ratio	Significance
Ni	Season	1	0.021	0.626	p=0.452
	Method	1	0.001	0.017	p=0.899
	Season*Method	1	0.018	0.530	p=0.487
	Site {season* method}	8	0.034		
Pb	Season	1	0.133	5.328	p=0.050
	Method	1	0.003	0.116	p=0.742
	Season*Method	1	0.016	0.629	p=0.450
	Site{season* method}	8	0.025		
Se	Season	1	0.019	0.817	p=0.392
	Method	1	0.006	0.276	p=0.614
	Season*Method	1	0.000	0.001	p=0.971
	Site{season* method}	8	0.023		
Si	Season	1	0.000	0.074	p=0.792
	Method	1	0.000	0.056	p=0.819
	Season*Method	1	0.003	0.460	p=0.517
	Site{season* method}	8	0.006		
Zn	Season	1	0.001	0.355	p=0.568
	Method	1	0.000	0.004	p=0.951
	Season*Method	1	0.000	0.073	p=0.794
	Site{season* method}	8	0.004		

Appendix Table 3. Analysis of Variance for differences in transformed metal concentration ($\log_e$(concentration+1)) in sediments from Station S2 within two seasons using two sampling methods.

Metal	Source of variation	DF	MS	F-ratio	Significance
Al	Season	1	0.120	6.752	p=0.015
	Method	1	0.046	2.604	p=0.117
	Season*Method	1	0.001	0.071	p=0.792
	Error	29	0.018		
As	Season	1	0.100	3.819	p=0.060
	Method	1	0.000	0.000	p=0.999
	Season*Method	1	0.135	5.141	p=0.031
	Error	29	0.132		
Cd	Season	1	0.004	5.734	p=0.023
	Method	1	0.001	1.917	p=0.177
	Season*Method	1	0.001	1.893	p=0.179
	Error	29	0.001		
Co	Season	1	0.206	12.111	p=0.002
	Method	1	0.000	0.010	p=0.919
	Season*Method	1	0.045	2.673	p=0.113
	Error	29	0.017		
Cr	Season	1	0.014	0.360	p=0.553
	Method	1	0.001	0.026	p=0.873
	Season*Method	1	0.011	0.287	p=0.596
	Error	29	0.037		
Cu	Season	1	0.015	0.544	p=0.467
	Method	1	0.000	0.005	p=0.945
	Season*Method	1	0.017	0.602	p=0.444
	Error	29	0.028		
Fe	Season	1	0.023	1.742	p=0.197
	Method	1	0.000	0.030	p=0.864
	Season*Method	1	0.027	2.022	p=0.166
	Error	29	0.013		
Hg	Season	1	0.002	9.464	p=0.005
	Method	1	0.000	0.592	p=0.448
	Season*Method	1	0.000		
	Error	29	0.000		
Mg	Season	1	0.019	18.609	p<0.001
	Method	1	0.000	0.233	p=0.633
	Season*Method	1	0.002	2.146	p=0.154
	Error	29	0.001		
Mn	Season	1	0.047	11.405	p=0.002
	Method	1	0.000	0.022	p=0.884
	Season*Method	1	0.006	1.363	p=0.252
	Error	29	0.004		

(Appendix Table 3 continued over)

Metal	Source of variation	DF	MS	F-ratio	Significance
Ni	Season	1	0.056	3.503	p=0.071
	Method	1	0.015	0.915	p=0.347
	Season*Method	1	0.006	0.372	p=0.547
	Error	29	0.016		
Pb	Season	1	0.004	0.237	p=0.630
	Method	1	0.020	1.090	p=0.305
	Season*Method	1	0.020	1.090	p=0.305
	Error	29	0.019		
Se	Season	1	0.002	1.093	p=0.304
	Method	1	0.001	0.508	p=0.482
	Season*Method	1	0.002	1.056	p=0.313
	Error	29	0.002		
Si	Season	1	0.047	3.536	p=0.070
	Method	1	0.000	0.018	p=0.895
	Season*Method	1	0.013	0.983	p=0.330
	Error	29	0.013		
Zn	Season	1	0.003	0.127	p=0.724
	Method	1	0.022	1.068	p=0.310
	Season*Method	1	0.018	0.887	p=0.354
	Error	29	0.020		

Appendix Table 4. Analysis of Variance for differences in transformed metal concentration ($\log_e$(concentration+1)) in sediments from Station S5 within two seasons using two sampling methods.

Metal	Source of variation	DF	MS	F-ratio	Significance
Al	Season	1	0.001	0.268	p=0.619
	Method	1	0.002	0.621	p=0.453
	Season*Method	1	0.003	1.039	p=0.338
	Site{season* method}	8	0.003		
As	Season	1	0.067	0.440	p=0.526
	Method	1	0.045	0.293	p=0.603
	Season*Method	1	0.012		
	Site{season* method)	8	0.152		
Cd	Season	1	0.000	9.400	p=0.005
	Method	1	0.000	0.712	p=0.407
	Season*Method	1	0.000	6.276	p=0.019
	Site{season* method}	8	0.000		
Co	Season	1	0.232	1.706	p=0.228
	Method	1	0.070	0.514	p=0.494
	Season*Method	1	0.177	1.303	p=0.287
	Site{season* method}	8	0.136		
Cr	Season	1	0.018	0.681	p=0.433
	Method	1	0.006	0.205	p=0.663
	Season*Method	1	0.041	1.518	p=0.253
	Site{season* method}	8	0.027		
Cu	Season	1	0.000	0.007	p=0.935
	Method	1	0.005	0.147	p=0.711
	Season*Method	1	0.005	0.147	p=0.711
	Site{season* method}	8	0.031		
Fe	Season	1	0.002	0.036	p=0.855
	Method	1	0.006	0.082	p=0.782
	Season*Method	1	0.001	0.011	p=0.818
	Site{season* method}	8	0.069		
Hg	Season	1	0.000	1.886	p=0.182
	Method	1	0.000	0.114	p=0.739
	Season*Method	1	0.000	0.114	p=0.739
	Site{season* method}	8	0.000		
Mg	Season	1	0.001	0.912	p=0.368
	Method	1	0.000	0.312	p=0.592
	Season*Method	1	0.001	0.466	p=0.514
	Site{season* method}	8	0.001		
Mn	Season	1	0.003	0.113	p=0.746
	Method	1	0.001	0.030	p=0.868
	Season*Method	1	0.001	0.025	p=0.877
	Site{season* method}	8	0.030		

(Appendix Table 4 continued over)

Metal	Source of variation	DF	MS	F-ratio	Significance
Ni	Season	1	0.085	1.133	p=0.318
	Method	1	0.024	0.316	p=0.590
	Season*Method	1	0.001	0.014	p=0.908
	Site{Season*method}	8	0.075		
Pb	Season	1	0.158	0.374	p=0.558
	Method	1	0.398	0.944	p=0.360
	Season*Method	1	0.062	0.146	p=0.712
	Site{season* method}	8	0.422		
Se	Season	1	0.001	0.085	p=0.778
	Method	1	0.004	0.270	p=0.617
	Season*Method	1	0.020	1.328	p=0.282
	Site{season* method}	8	0.015		
Si	Season	1	0.001	0.094	p=0.767
	Method	1	0.009	1.419	p=0.268
	Season*Method	1	0.009	1.425	p=0.267
	Site{season* method}	8	0.006		
Zn	Season	1	0.028	1.267	p=0.293
	Method	1	0.017	0.757	p=0.410
	Season*Method	1	0.004	0.176	p=0.686
	Site{season* method}	8	0.022		

Appendix Table 5. Analysis of Variance for differences in transformed ($\log_e$(concentration+1)) metal concentration in sediments from Station S10 during the post-monsoon season at two stages of the tidal cycle 5 days apart.

Metal	Source of variation	D F	MS	F-ratio	Significance
Al	Tide	1	0.015	14.067	p=0.020
	Site {tide}	4	0.001		
As	Tide	1	0.003	0.098	p=0.781
	Site{tide}	4	0.034		
Cd	Tide	1	0.000	64.113	p=0.001
	Site{tide}	4	0.000		
Co	Tide	1	0.000	0.060	p=0.818
	Site{tide}	4			
Cr	Tide	1	0.028	1.845	p=0.246
	Site{tide}	4	0.015		
Cu	Tide	1	0.031	2.060	p=0.225
	Site{tide}	4	0.015		
Fe	Tide	1	0.000	0.056	p=0.824
	Site{tide}	4	0.004		
Hg	Tide	1	0.000	0.985	p=0.377
	Site{tide}	4	0.000		
Mg	Tide	1	0.004	2.252	p=0.208
	Site{tide}	4	0.002		
Mn	Tide	1	0.003	1.056	p=0.362
	Site{tide}	4	0.003		
Ni	Tide	1	0.000	0.019	p=0.897
	Site{tide}	4	0.017		
Pb	Tide	1	0.005	0.429	p=0.548
	Site{tide}	4	0.012		
Se	Tide	1	0.000	0.020	p=0.896
	Site{tide}	4	0.003		
Si	Tide	1	0.000	0.368	p=0.577
	Site{tide}	4	0.001		
Zn	Tide	1	0.002	5.708	p=0.075
	Site{tide}	4	0.000		

Appendix Table 6. Analysis of Variance for differences in transformed ($\log_e$(concentration+1)) metal concentration in sediments from Station S2 during the post-monsoon season at two stages of the tidal cycle 6 days apart.

Metal	Source of variation	DF	MS	F-ratio	Significance
A1	Tide	1	0.054	5.576	p=0.078
	Site{tide}	4	0.010		
As	Tide	1	0.046	0.862	p=0.406
	Site{tide}	4	0.054		
Cd	Tide	1	0.000	0.049	p=0.836
	Site{tide}	4	0.000		
Co	Tide	1	0.001	0.235	p=0.653
	Site{tide}	4			
Cr	Tide	1	0.133	1.534	p=0.283
	Site{tide}	4	0.087		
Cu	Tide	1	0.012	0.530	p=0.507
	Site{tide}	4	0.022		
Fe	Tide	1	0.004	0.895	p=0.398
	Site{tide}	4	0.004		
Mg	Tide	1	0.000	1.051	p=0.363
	Site{tide}	4	0.000		
Mn	Tide	1	0.000	0.039	p=0.852
	Site{tide}	4	0.004		
Ni	Tide	1	0.000	0.034	p=0.864
	Site{tide}	4	0.009		
Pb	Tide	1	0.022	1.714	p=0.261
	Site{tide}	4	0.013		
Se	Tide	1	0.000	0.005	p=0.946
	Site{tide}	4	0.002		
Si	Tide	1	0.042	6.139	p=0.068
	Site{tide}	4	0.007		
Zn	Tide	1	0.032	2.613	p=0.181
	Site{tide}	4	0.012		

Appendix Table 7. Analysis of Variance for differences in transformed (log_e(concentration+1)) metal concentration in sediments from Station S10 during the post-monsoon season from two station areas (sizes).

Metal	Source of variation	DF	MS	F-ratio	Significance
Al	Station area	1	0.086	1.575	p=0.278
	Site{station area}	4	0.055		
As	Station area	1	13.634	35.083	p=0.004
	Site{station area}	4	0.389		
Cd	Station area	1	0.000	64.113	p=0.001
	Site{station area}	4	0.000		
Co	Station area	1	1.154	15.050	p=0.018
	Site{station area}	4	0.077		
Cr	Station area	1	0.253	7.001	p=0.057
	Site{station area}	4	0.036		
Cu	Station area	1	0.247	3.285	p=0.144
	Site{station area}	4	0.075		
Fe	Station area	1	1.918	19.081	p=0.012
	Site{station area}	4	0.101		
Hg	Station area	1	0.000	0.985	p=0.377
	Site{station area}	4	0.000		
Mg	Station area	1	0.000	0.001	p=0.980
	Site{station area}	4	0.005		
Mn	Station area	1	2.947	5.974	p=0.071
	Site{station area}	4	0.493		
Ni	Station area	1	0.290	4.338	p=0.106
	Site{station area}	4	0.067		
Pb	Station area	1	2.041	7.909	p=0.048
	Site{station area}	4	0.258		
Se	Station area	1	0.001	0.135	p=0.732
	Site{station area}	4	0.004		
Si	Station area	1	0.072	2.271	p=0.206
	Site{station area}	4	0.032		
Zn	Station area	1	0.084	2.790	p=0.170
	Site{station area}	4	0.030		

Appendix Table 8a. Aluminium (Al) concentrations (averaged over two seasons) in sediments from grab samples collected at eight locations. Metal concentrations are in mg kg^{-1} (dry weight). n = sample size. S.D. = standard deviation. Concentrations at all locations were significantly different ($p<=0.05$ by Tukey's Test) to each other except for S10 & S6, S3 & S4, S3 & S7, and S4 & S7.

Sampling Station	n	Mean	S.D.	Range
S1	19	8.36	0.60	7.80-10.20
S10	17	3.62	0.26	3.27-4.13
S2	18	1.42	0.46	0.88-2.77
S3	18	0.45	0.15	0.30-0.80
S4	18	0.26	0.06	0.20-0.38
S5	18	0.73	0.08	0.61-0.88
S6	17	3.28	0.55	2.41-4.27
S7	18	0.42	0.05	0.34-0.56

Appendix Table 8b. Aluminium (Al) concentrations in sediments from eight locations within two seasons. Metal concentrations are in mg kg^{-1} (dry weight). n = sample size. S.D. = standard deviation. large = large sampling station area. +*x* days = samples collected *x* days after the other grab and diver samples from the same location.

Season	Sampling Station	Method	n	Mean	S.D.	Range
Pre-monsoon	S1	Grab	10	8.75	0.59	8.17-10.20
Pre-monsoon	S10	Grab	9	3.84	0.13	3.69-4.13
Pre-monsoon	S10	Diver	9	3.87	0.14	3.60-4.15
Pre-monsoon	S2	Grab	9	1.29	0.62	0.88-2.77
Pre-monsoon	S2	Diver	6	1.09	0.12	0.96-1.28
Pre-monsoon	S3	Grab	9	0.34	0.04	0.30-0.41
Pre-monsoon	S4	Grab	9	0.23	0.06	0.20-0.38
Pre-monsoon	S5	Grab	9	0.71	0.09	0.61-0.83
Pre-monsoon	S5	Diver	9	0.71	0.03	0.67-0.78
Pre-monsoon	S6	Grab	8	2.85	0.31	2.41-3.47
Pre-monsoon	S7	Grab	9	0.43	0.06	0.34-0.56
Post-monsoon	S1	Grab	9	7.93	0.10	7.80-8.14
Post-monsoon	S10	Grab	8	3.37	0.07	3.27-3.46
Post-monsoon	S10	Diver	9	3.29	0.09	3.10-3.39
Post-monsoon	S10 (+5 days)	Grab	9	3.63	0.12	3.50-3.79
Post-monsoon	S10 (large)	Grab	9	4.10	0.86	3.08-5.33
Post-monsoon	S2	Grab	9	1.56	0.17	1.18-1.77
Post-monsoon	S2	Diver	9	1.34	0.17	1.10-1.63
Post-monsoon	S2 (+6 days)	Grab	9	1.85	0.16	1.57-2.10
Post-monsoon	S3	Grab	9	0.55	0.14	0.38-0.80
Post-monsoon	S4	Grab	9	0.29	0.04	0.25-0.35
Post-monsoon	S5	Grab	9	0.76	0.07	0.68-0.88
Post-monsoon	S5	Diver	9	0.70	0.04	0.65-0.76
Post-monsoon	S6	Grab	9	3.66	0.43	2.83-4.27
Post-monsoon	S7	Grab	9	0.41	0.05	0.36-0.52

Appendix Table 9a. Arsenic (As) concentrations (averaged over two seasons) in sediments from grab samples collected at eight locations. Metal concentrations are in mg kg^{-1} (dry weight). n = sample size. S.D. = standard deviation. Means with the same superscript indicate a significant difference between locations ($p<=0.05$ by Tukey's Test).

Sampling Station	n	Mean	S.D.	Range
S1	19	15.4^{abc}	1.6	13.0-20.0
S10	17	17.6^{defg}	2.2	15.0-21.0
S2	18	18.2^{hijk}	5.1	12.0-34.0
S3	18	3.4^{adhlmn}	0.9	1.0-4.0
S4	18	5.2^{beiop}	1.0	4.0-7.0
S5	18	7.8^{cfjlq}	1.4	5.0-10.0
S6	17	27.3^{moqr}	4.5	16.0-36.0
S7	18	9.7^{gknpr}	2.3	6.0-14.0

Appendix Table 9b. Arsenic (As) concentrations in sediments from eight locations within two seasons. Metal concentrations are in mg kg^{-1} (dry weight). n = sample size. S.D. = standard deviation. large = large sampling station area. +*x* days = samples collected *x* days after the other grab and diver samples from the same location.

Season	Sampling Station	Method	n	Mean	S.D.	Range
Pre-monsoon	S1	Grab	10	15.6	2.0	13.0-20.0
Pre-monsoon	S10	Grab	9	17.6	2.6	15.0-21.0
Pre-monsoon	S10	Diver	9	17.6	2.2	15.0-21.0
Pre-monsoon	S2	Grab	9	20.7	5.9	14.0-34.0
Pre-monsoon	S2	Diver	6	17.5	1.0	16.0-19.0
Pre-monsoon	S3	Grab	9	3.7	0.7	2.0-4.0
Pre-monsoon	S4	Grab	9	5.2	1.1	4.0-7.0
Pre-monsoon	S5	Grab	9	7.6	0.9	6.0-9.0
Pre-monsoon	S5	Diver	9	7.9	1.3	6.0-10.0
Pre-monsoon	S6	Grab	8	27.9	6.0	16.0-36.0
Pre-monsoon	S7	Grab	9	8.7	2.0	6.0-12.0
Post-monsoon	S1	Grab	9	15.1	1.1	13.0-16.0
Post-monsoon	S10	Grab	8	17.8	1.8	15.0-20.0
Post-monsoon	S10	Diver	9	17.7	0.7	17.0-19.0
Post-monsoon	S10 (+5 days)	Grab	9	17.4	2.3	15.0-21.0
Post-monsoon	S10 (large)	Grab	9	125.2	59.8	73.0-214.0
Post-monsoon	S2	Grab	9	15.7	2.3	12.0-18.0
Post-monsoon	S2	Diver	9	17.9	1.8	15.0-21.0
Post-monsoon	S2 (+6 days)	Grab	9	14.1	2.6	11.0-19.0
Post-monsoon	S3	Grab	9	3.1	1.1	1.0-4.0
Post-monsoon	S4	Grab	9	5.1	1.1	4.0-7.0
Post-monsoon	S5	Grab	9	8.1	1.8	5.0-10.0
Post-monsoon	S5	Diver	9	9.0	1.0	8.0-11.0
Post-monsoon	S6	Grab	9	26.8	3.0	21.0-30.0
Post-monsoon	S7	Grab	9	10.7	2.3	7.0-14.0

Appendix Table 10a. Cadmium (Cd) concentrations (averaged over two seasons) in sediments from grab samples collected at eight locations. Metal concentrations are in mg kg^{-1} (dry weight). n = sample size. S.D. = standard deviation. Means with the same superscript indicate a significant difference between locations (p<=0.05 by Tukey's Test).

Sampling Station	n	Mean	S.D.	Range
S1	19	0.012^{abcd}	0.005	0.01-0.03
S10	17	0.026^{e}	0.007	0.02-0.04
S2	18	0.055^{a}	0.012	0.02-0.07
S3	18	0.063^{bef}	0.037	0.04-0.21
S4	18	0.051^{c}	0.005	0.04-0.06
S5	18	0.041	0.008	0.03-0.06
S6	17	0.024^{f}	0.005	0.02-0.03
S7	18	0.052^{d}	0.005	0.04-0.06

Appendix Table 10b. Cadmium (Cd) concentrations in sediments from eight locations within two seasons. Metal concentrations are in mg kg^{-1} (dry weight). n = sample size. S.D. = standard deviation. large = large sampling station area. +*x* days = samples collected *x* days after the other grab and diver samples from the same location.

Season	Sampling Station	Method	n	Mean	S.D.	Range
Pre-monsoon	S1	Grab	10	0.014	0.007	0.01-0.03
Pre-monsoon	S10	Grab	9	0.023	0.005	0.02-0.03
Pre-monsoon	S10	Diver	9	0.021	0.003	0.02-0.03
Pre-monsoon	S2	Grab	9	0.050	0.014	0.02-0.07
Pre-monsoon	S2	Diver	6	0.050	0.000	0.05-0.05
Pre-monsoon	S3	Grab	9	0.049	0.003	0.04-0.05
Pre-monsoon	S4	Grab	9	0.050	0.000	0.05-0.05
Pre-monsoon	S5	Grab	9	0.047	0.007	0.04-0.06
Pre-monsoon	S5	Diver	9	0.043	0.005	0.04-0.05
Pre-monsoon	S6	Grab	8	0.025	0.005	0.02-0.03
Pre-monsoon	S7	Grab	9	0.051	0.003	0.05-0.06
Post-monsoon	S1	Grab	9	0.010	0.000	0.01-0.01
Post-monsoon	S10	Grab	8	0.029	0.008	0.02-0.04
Post-monsoon	S10	Diver	9	0.020	0.000	0.02-0.02
Post-monsoon	S10 (+5 days)	Grab	9	0.020	0.000	0.02-0.02
Post-monsoon	S10 (large)	Grab	9	0.020	0.000	0.02-0.02
Post-monsoon	S2	Grab	9	0.060	0.007	0.05-0.07
Post-monsoon	S2	Diver	9	0.089	0.054	0.05-0.22
Post-monsoon	S2 (+6 days)	Grab	9	0.059	0.012	0.04-0.07
Post-monsoon	S3	Grab	9	0.077	0.050	0.05-0.21
Post-monsoon	S4	Grab	9	0.052	0.007	0.04-0.06
Post-monsoon	S5	Grab	9	0.036	0.005	0.03-0.04
Post-monsoon	S5	Diver	9	0.042	0.007	0.04-0.06
Post-monsoon	S6	Grab	9	0.023	0.005	0.02-0.03
Post-monsoon	S7	Grab	9	0.053	0.007	0.04-0.06

Appendix Table 11a. Cobalt (Co) concentrations (averaged over two seasons) in sediments from grab samples collected at eight locations. Metal concentrations are in mg kg^{-1} (dry weight). n = sample size. S.D. = standard deviation. Concentrations at all locations were significantly different (p<=0.05 by Tukey's Test) to each other except for S10 & S6, S3 & S4, S3 & S7, S4 & S7, and S5 & S7.

Sampling Station	n	Mean	S.D.	Range
S1	19	14.53	1.07	12.0-17.0
S10	17	9.29	1.11	7.0-11.0
S2	18	5.94	0.87	5.0-8.0
S3	18	2.50	0.79	1.0-4.0
S4	18	2.22	0.55	1.0-3.0
S5	18	3.72	0.90	2.0-5.0
S6	17	9.24	1.20	7.0-11.0
S7	18	2.89	1.02	1.0-5.0

Appendix Table 11b. Cobalt (Co) concentrations in sediments from eight locations within two seasons. Metal concentrations are in mg kg^{-1} (dry weight). n = sample size. S.D. = standard deviation. large = large sampling station area. +*x* days = samples collected *x* days after the other grab and diver samples from the same location.

Season	Sampling Station	Method	n	Mean	S.D.	Range
Pre-monsoon	S1	Grab	10	14.5	1.3	12.0-17.0
Pre-monsoon	S10	Grab	9	9.0	1.3	7.0-10.0
Pre-monsoon	S10	Diver	9	8.8	0.8	8.0-10.0
Pre-monsoon	S2	Grab	9	5.7	1.0	5.0-8.0
Pre-monsoon	S2	Diver	6	5.2	1.0	4.0-6.0
Pre-monsoon	S3	Grab	9	2.1	0.8	1.0-3.0
Pre-monsoon	S4	Grab	9	2.1	0.3	2.0-3.0
Pre-monsoon	S5	Grab	9	3.7	0.9	2.0-5.0
Pre-monsoon	S5	Diver	9	2.8	1.0	1.0-4.0
Pre-monsoon	S6	Grab	8	8.4	1.1	7.0-10.0
Pre-monsoon	S7	Grab	9	2.1	0.6	1.0-3.0
Post-monsoon	S1	Grab	9	14.6	0.9	13.0-16.0
Post-monsoon	S10	Grab	8	9.6	0.7	9.0-11.0
Post-monsoon	S10	Diver	9	10.0	0.7	9.0-11.0
Post-monsoon	S10 (+5 days)	Grab	9	9.6	0.7	9.0-11.0
Post-monsoon	S10 (large)	Grab	9	17.3	4.0	12.0-24.0
Post-monsoon	S2	Grab	9	6.2	0.7	5.0-7.0
Post-monsoon	S2	Diver	9	6.8	1.0	5.0-8.0
Post-monsoon	S2 (+6 days)	Grab	9	6.1	0.8	5.0-7.0
Post-monsoon	S3	Grab	9	2.9	0.6	2.0-4.0
Post-monsoon	S4	Grab	9	2.3	0.7	1.0-3.0
Post-monsoon	S5	Grab	9	3.8	1.0	2.0-5.0
Post-monsoon	S5	Diver	9	4.0	0.9	3.0-5.0
Post-monsoon	S6	Grab	9	10.0	0.7	9.0-11.0
Post-monsoon	S7	Grab	9	3.7	0.7	3.0-5.0

Appendix Table 12a. Chromium (Cr) concentrations (averaged over two seasons) in sediments from grab samples collected at eight locations. Metal concentrations are in mg kg^{-1} (dry weight). n = sample size. S.D. = standard deviation. Concentrations at all locations were significantly different ($p<=0.05$ by Tukey's Test) to each other except for S1 & S10, S2 & S6, S3 & S4, S3 & S7, and S5 & S7.

Sampling Station	n	Mean	S.D.	Range
S1	19	82.1	4.9	73.0-95.0
S10	17	76.8	6.3	69.0-88.0
S2	18	54.9	14.2	40.0-103.0
S3	18	11.5	2.7	7.0-17.0
S4	18	8.9	2.4	5.0-15.0
S5	18	20.3	2.6	17.0-27.0
S6	17	47.4	8.6	36.0-61.0
S7	18	15.0	1.6	12.0-19.0

Appendix Table 12b. Chromium (Cr) concentrations in sediments from eight locations within two seasons. Metal concentrations are in mg kg^{-1} (dry weight). n = sample size. S.D. = standard deviation. large = large sampling station area. +*x* days = samples collected *x* days after the other grab and diver samples from the same location.

Season	Sampling Station	Method	n	Mean	S.D.	Range
Pre-monsoon	S1	Grab	10	84.7	4.4	81.0-95.0
Pre-monsoon	S10	Grab	9	77.4	5.4	69.0-85.0
Pre-monsoon	S10	Diver	9	77.8	8.5	68.0-96.0
Pre-monsoon	S2	Grab	9	52.0	7.5	40.0-63.0
Pre-monsoon	S2	Diver	6	53.3	8.0	46.0-68.0
Pre-monsoon	S3	Grab	9	10.2	2.2	7.0-13.0
Pre-monsoon	S4	Grab	9	8.4	2.7	6.0-15.0
Pre-monsoon	S5	Grab	9	20.0	1.5	18.0-23.0
Pre-monsoon	S5	Diver	9	20.9	1.1	20.0-23.0
Pre-monsoon	S6	Grab	8	40.3	3.6	36.0-47.0
Pre-monsoon	S7	Grab	9	15.6	1.7	13.0-19.0
Post-monsoon	S1	Grab	9	79.1	3.9	73.0-84.0
Post-monsoon	S10	Grab	8	76.1	7.5	69.0-88.0
Post-monsoon	S10	Diver	9	73.0	6.1	62.0-79.0
Post-monsoon	S10 (+5 days)	Grab	9	83.3	10.4	71.0-102.0
Post-monsoon	S10 (large)	Grab	9	98.9	15.0	77.0-116.0
Post-monsoon	S2	Grab	9	57.9	18.8	43.0-103.0
Post-monsoon	S2	Diver	9	53.8	8.8	40.0-65.0
Post-monsoon	S2 (+6 days)	Grab	9	47.1	5.9	37.0-58.0
Post-monsoon	S3	Grab	9	12.8	2.7	9.0-17.0
Post-monsoon	S4	Grab	9	9.4	2.2	5.0-13.0
Post-monsoon	S5	Grab	9	20.7	3.5	17.0-27.0
Post-monsoon	S5	Diver	9	18.7	2.4	16.0-22.0
Post-monsoon	S6	Grab	9	53.7	6.5	45.0-61.0
Post-monsoon	S7	Grab	9	14.4	1.3	12.0-16.0

Appendix Table 13a. Copper (Cu) concentrations (averaged over two seasons) in sediments from grab samples collected at eight locations. Metal concentrations are in mg kg^{-1} (dry weight). n = sample size. S.D. = standard deviation. Means with the same superscript indicate a significant difference between locations (p<=0.05 by Tukey's Test).

Sampling Station	n	Mean	S.D.	Range
S1	19	$19.3^{abcdefg}$	6.4	14.0-44.0
S10	17	6.8^{ahijk}	0.9	6.0-8.0
S2	18	5.0^{blmn}	0.9	4.0-7.0
S3	18	2.8^{chlo}	0.6	2.0-4.0
S4	18	2.6^{dimp}	0.6	2.0-4.0
S5	18	3.3^{ejq}	0.6	2.0-4.0
S6	17	7.5^{fopqr}	1.0	6.0-9.0
S7	18	2.8^{gknr}	0.5	2.0-4.0

Appendix Table 13b. Copper (Cu) concentrations in sediments from eight locations within two seasons. Metal concentrations are in mg kg^{-1} (dry weight). n = sample size. S.D. = standard deviation. large = large sampling station area. +*x* days = samples collected *x* days after the other grab and diver samples from the same location.

Season	Sampling Station	Method	n	Mean	S.D.	Range
Pre-monsoon	S1	Grab	10	21.6	8.2	15.0-44.0
Pre-monsoon	S10	Grab	9	6.7	0.7	6.0-8.0
Pre-monsoon	S10	Diver	9	6.9	1.2	5.0-8.0
Pre-monsoon	S2	Grab	9	5.0	1.0	4.0-7.0
Pre-monsoon	S2	Diver	6	5.3	1.2	4.0-7.0
Pre-monsoon	S3	Grab	9	2.7	0.5	2.0-3.0
Pre-monsoon	S4	Grab	9	2.4	0.5	2.0-3.0
Pre-monsoon	S5	Grab	9	3.3	0.7	2.0-4.0
Pre-monsoon	S5	Diver	9	3.3	0.7	2.0-4.0
Pre-monsoon	S6	Grab	8	7.8	1.2	6.0-9.0
Pre-monsoon	S7	Grab	9	2.8	0.7	2.0-4.0
Post-monsoon	S1	Grab	9	16.7	1.4	14.0-19.0
Post-monsoon	S10	Grab	8	7.0	1.1	6.0-8.0
Post-monsoon	S10	Diver	9	6.8	1.5	4.0-9.0
Post-monsoon	S10 (+5 days)	Grab	9	6.2	0.8	5.0-7.0
Post-monsoon	S10 (large)	Grab	9	9.2	2.2	6.0-12.0
Post-monsoon	S2	Grab	9	5.0	0.9	4.0-6.0
Post-monsoon	S2	Diver	9	4.8	1.0	3.0-6.0
Post-monsoon	S2 (+6 days)	Grab	9	5.3	0.7	4.0-6.0
Post-monsoon	S3	Grab	9	3.0	0.7	2.0-4.0
Post-monsoon	S4	Grab	9	2.7	0.7	2.0-4.0
Post-monsoon	S5	Grab	9	3.2	0.4	3.0-4.0
Post-monsoon	S5	Diver	9	3.4	0.7	3.0-5.0
Post-monsoon	S6	Grab	9	7.2	0.8	6.0-8.0
Post-monsoon	S7	Grab	9	2.8	0.4	2.0-3.0

Appendix Table 14a. Iron (Fe) concentrations (averaged over two seasons) in sediments from grab samples collected at eight locations. Metal concentrations are in mg kg^{-1} (dry weight). n = sample size. S.D. = standard deviation. Concentrations at all locations were significantly different (p<=0.05 by Tukey's Test) to each other except for S1 & S6, S10 & S2, S10 & S6, and S3 & S4.

Sampling Station	n	Mean	S.D.	Range
S1	19	4.38	0.15	4.21-4.86
S10	17	3.61	0.16	3.31-3.88
S2	18	2.96	0.51	2.57-4.67
S3	18	0.22	0.08	0.11-0.42
S4	18	0.14	0.03	0.09-0.20
S5	18	1.46	0.20	0.98-1.87
S6	17	4.34	0.40	3.29-4.81
S7	18	0.84	0.17	0.61-1.26

Appendix Table 14b. Iron (Fe) concentrations in sediments from eight locations within two seasons. Metal concentrations are in mg kg^{-1} (dry weight). n = sample size. S.D. = standard deviation. large = large sampling station area. +*x* days = samples collected *x* days after the other grab and diver samples from the same location.

Season	Sampling Station	Method	n	Mean	S.D.	Range
Pre-monsoon	S1	Grab	10	4.34	0.20	4.21-4.86
Pre-monsoon	S10	Grab	9	3.59	0.20	3.31-3.88
Pre-monsoon	S10	Diver	9	3.61	0.18	3.38-3.87
Pre-monsoon	S2	Grab	9	3.20	0.63	2.66-4.67
Pre-monsoon	S2	Diver	6	3.00	0.76	2.41-4.52
Pre-monsoon	S3	Grab	9	0.17	0.03	0.11-0.21
Pre-monsoon	S4	Grab	9	0.13	0.03	0.09-0.20
Pre-monsoon	S5	Grab	9	1.43	0.11	1.24-1.59
Pre-monsoon	S5	Diver	9	1.52	0.25	1.27-1.92
Pre-monsoon	S6	Grab	8	4.22	0.49	3.29-4.76
Pre-monsoon	S7	Grab	9	0.77	0.14	0.61-1.02
Post-monsoon	S1	Grab	9	4.42	0.04	4.37-4.49
Post-monsoon	S10	Grab	8	3.64	0.10	3.50-3.81
Post-monsoon	S10	Diver	9	3.58	0.08	3.42-3.67
Post-monsoon	S10 (+5 days)	Grab	9	3.68	0.20	3.47-3.95
Post-monsoon	S10 (large)	Grab	9	8.39	2.18	5.71-11.48
Post-monsoon	S2	Grab	9	2.72	0.12	2.57-2.93
Post-monsoon	S2	Diver	9	2.98	0.39	2.18-3.57
Post-monsoon	S2 (+6 days)	Grab	9	2.62	0.21	2.34-2.90
Post-monsoon	S3	Grab	9	0.27	0.09	0.18-0.42
Post-monsoon	S4	Grab	9	0.15	0.02	0.12-0.19
Post-monsoon	S5	Grab	9	1.50	0.26	0.98-1.87
Post-monsoon	S5	Diver	9	1.53	0.12	1.40-1.71
Post-monsoon	S6	Grab	9	4.44	0.29	3.93-4.81
Post-monsoon	S7	Grab	9	0.91	0.18	0.73-1.26

Appendix Table 15a. Mercury (Hg) concentrations (averaged over two seasons) in sediments from grab samples collected at eight locations. Metal concentrations are in mg kg^{-1} (dry weight). n = sample size. S.D. = standard deviation. bdl = below detection limit (<0.05).

Sampling Station	n	Mean	S.D.	Range
S1	19	0.048	0.016	<0.05-0.08
S10	17	0.032	0.007	<0.05-0.05
S2	18	0.036	0.017	<0.05-0.09
S3	18	0.033	0.014	<0.05-0.09
S4	18	bdl		
S5	18	0.033	0.012	<0.05-0.08
S6	17	0.036	0.022	<0.05-0.12
S7	18	0.036	0.017	<0.05-0.10

Appendix Table 15b. Mercury (Hg) concentrations in sediments from eight locations within two seasons. Metal concentrations are in mg kg^{-1} (dry weight). n = sample size. S.D. = standard deviation. large = large sampling station area. +*x* days = samples collected *x* days after the other grab and diver samples from the same location.

Season	Sampling Station	Method	n	Mean	S.D.	Range
Pre-monsoon	S1	Grab	10	0.047	0.013	<0.05-0.06
Pre-monsoon	S10	Grab	9	0.032	0.007	<0.05-0.05
Pre-monsoon	S10	Diver	9	0.047	0.018	<0.05-0.08
Pre-monsoon	S2	Grab	9	0.041	0.023	<0.05-0.09
Pre-monsoon	S2	Diver	6	0.048	0.016	<0.05-0.07
Pre-monsoon	S3	Grab	9	0.037	0.020	<0.05-0.09
Pre-monsoon	S4	Grab	9	bdl		
Pre-monsoon	S5	Grab	9	0.036	0.017	<0.05-0.08
Pre-monsoon	S5	Diver	9	0.033	0.010	<0.05-0.06
Pre-monsoon	S6	Grab	8	0.044	0.032	<0.05-0.12
Pre-monsoon	S7	Grab	9	0.042	0.023	<0.05-0.10
Post-monsoon	S1	Grab	9	0.050	0.021	<0.05-0.08
Post-monsoon	S10	Grab	8	0.033	0.007	<0.05-0.05
Post-monsoon	S10	Diver	9	bdl		
Post-monsoon	S10 (+5 days)	Grab	9	bdl		
Post-monsoon	S10 (large)	Grab	9	bdl		
Post-monsoon	S2	Grab	9	bdl		
Post-monsoon	S2	Diver	9	bdl		
Post-monsoon	S2 (+6 days)	Grab	9	bdl		
Post-monsoon	S3	Grab	9	bdl		
Post-monsoon	S4	Grab	9	bdl		
Post-monsoon	S5	Grab	9	bdl		
Post-monsoon	S5	Diver	9	bdl		
Post-monsoon	S6	Grab	9	bdl		
Post-monsoon	S7	Grab	9	bdl		

Appendix Table 16a. Magnesium (Mg) concentrations (averaged over two seasons) in sediments from grab samples collected at eight locations. Metal concentrations are in mg kg^{-1} (dry weight). n = sample size. S.D. = standard deviation. Concentrations at all locations were significantly different (p<=0.05 by Tukey's Test) to each other except for S4 & S5, S4 & S6, S4 & S7, S5 & S6, S5 & S7, and S6 & S7.

Sampling Station	n	Mean	S.D.	Range
S1	19	0.656	0.055	0.57-0.73
S10	17	1.352	0.067	1.23-1.44
S2	18	1.524	0.137	1.33-1.99
S3	18	2.059	0.077	1.97-2.24
S4	18	1.768	0.066	1.64-1.87
S5	18	1.877	0.034	1.79-1.96
S6	17	1.809	0.197	1.46-2.12
S7	18	1.886	0.036	1.80-1.95

Appendix Table 16b. Magnesium (Mg) concentrations in sediments from eight locations within two seasons. Metal concentrations are in mg kg^{-1} (dry weight). n = sample size. S.D. = standard deviation. large = large sampling station area. +*x* days = samples collected *x* days after the other grab and diver samples from the same location.

Season	Sampling Station	Method	n	Mean	S.D.	Range
Pre-monsoon	S1	Grab	10	0.616	0.047	0.57-0.73
Pre-monsoon	S10	Grab	9	1.308	0.059	1.23-1.40
Pre-monsoon	S10	Diver	9	1.381	0.050	1.31-1.49
Pre-monsoon	S2	Grab	9	1.607	0.148	1.52-1.99
Pre-monsoon	S2	Diver	6	1.575	0.032	1.52-1.62
Pre-monsoon	S3	Grab	9	2.114	0.064	2.04-2.24
Pre-monsoon	S4	Grab	9	1.822	0.033	1.78-1.87
Pre-monsoon	S5	Grab	9	1.881	0.018	1.86-1.92
Pre-monsoon	S5	Diver	9	1.923	0.024	1.88-1.96
Pre-monsoon	S6	Grab	8	1.964	0.125	1.76-2.12
Pre-monsoon	S7	Grab	9	1.879	0.017	1.86-1.90
Post-monsoon	S1	Grab	9	0.700	0.013	0.69-0.73
Post-monsoon	S10	Grab	8	1.401	0.034	1.34-1.44
Post-monsoon	S10	Diver	9	1.404	0.030	1.34-1.44
Post-monsoon	S10 (+5 days)	Grab	9	1.336	0.068	1.25-1.44
Post-monsoon	S10 (large)	Grab	9	1.404	0.127	1.21-1.55
Post-monsoon	S2	Grab	9	1.441	0.052	1.33-1.50
Post-monsoon	S2	Diver	9	1.494	0.033	1.45-1.55
Post-monsoon	S2 (+6 days)	Grab	9	1.464	0.032	1.41-1.52
Post-monsoon	S3	Grab	9	2.003	0.039	1.97-2.08
Post-monsoon	S4	Grab	9	1.713	0.039	1.64-1.76
Post-monsoon	S5	Grab	9	1.872	0.046	1.79-1.96
Post-monsoon	S5	Diver	9	1.868	0.022	1.84-1.91
Post-monsoon	S6	Grab	9	1.671	0.136	1.46-1.88
Post-monsoon	S7	Grab	9	1.893	0.049	1.80-1.95

Appendix Table 17a. Manganese (Mn) concentrations (averaged over two seasons) in sediments from grab samples collected at eight locations. Metal concentrations are in mg kg^{-1} (dry weight). n = sample size. S.D. = standard deviation. Concentrations at all locations were significantly different ($p<=0.05$ by Tukey's Test) to each other except for S10 & S2, S10 & S6, S2 & S6, S3 & S4, and S5 & S7.

Sampling Station	n	Mean	S.D.	Range
S1	19	620.5	37.0	585-724
S10	17	425.2	24.4	392-486
S2	18	364.0	34.4	320-456
S3	18	85.1	7.4	76-104
S4	18	74.2	3.2	69-81
S5	18	202.8	14.0	177-219
S6	17	422.7	29.5	356-464
S7	18	173.1	28.4	146-250

Appendix Table 17b. Manganese (Mn) concentrations in sediments from eight locations within two seasons. Metal concentrations are in mg kg^{-1} (dry weight). n = sample size. S.D. = standard deviation. large = large sampling station area. +*x* days = samples collected *x* days after the other grab and diver samples from the same location.

Season	Sampling Station	Method	n	Mean	S.D.	Range
Pre-monsoon	S1	Grab	10	625.8	51.0	585-724
Pre-monsoon	S10	Grab	9	424.3	26.9	395-486
Pre-monsoon	S10	Diver	9	425.7	18.0	408-453
Pre-monsoon	S2	Grab	9	383.2	36.6	330-456
Pre-monsoon	S2	Diver	6	370.7	12.2	353-386
Pre-monsoon	S3	Grab	9	83.6	4.4	76-91
Pre-monsoon	S4	Grab	9	73.6	3.0	69-79
Pre-monsoon	S5	Grab	9	205.7	13.0	183-219
Pre-monsoon	S5	Diver	9	206.0	16.2	185-235
Pre-monsoon	S6	Grab	8	412.8	30.9	356-461
Pre-monsoon	S7	Grab	9	167.3	17.2	150-192
Post-monsoon	S1	Grab	9	614.7	9.1	602-630
Post-monsoon	S10	Grab	8	426.3	23.0	392-456
Post-monsoon	S10	Diver	9	423.7	12.1	401-439
Post-monsoon	S10 (+5 days)	Grab	9	439.3	21.6	412-480
Post-monsoon	S10 (large)	Grab	9	1119.1	608.5	612-2054
Post-monsoon	S2	Grab	9	344.8	18.6	320-365
Post-monsoon	S2	Diver	9	352.8	17.5	324-382
Post-monsoon	S2 (+6 days)	Grab	9	343.0	21.7	323-380
Post-monsoon	S3	Grab	9	86.7	9.7	79-104
Post-monsoon	S4	Grab	9	74.8	3.4	70-81
Post-monsoon	S5	Grab	9	200.0	15.3	177-218
Post-monsoon	S5	Diver	9	203.4	6.5	196-212
Post-monsoon	S6	Grab	9	431.6	26.8	383-464
Post-monsoon	S7	Grab	9	178.9	36.6	146-250

Appendix Table 18a. Nickel (Ni) concentrations (averaged over two seasons) in sediments from grab samples collected at eight locations. Metal concentrations are in mg kg^{-1} (dry weight). n = sample size. S.D. = standard deviation. Concentrations at all locations were significantly different ($p<=0.05$ by Tukey's Test) to each other except for S10 & S6, S3 & S4, S3 & S5, S3 & S7, and S5 & S7.

Sampling Station	n	Mean	S.D.	Range
S1	19	46.4	2.8	40.0-52.0
S10	17	25.4	2.3	22.0-30.0
S2	18	13.6	2.1	11.0-19.0
S3	18	7.4	1.2	6.0-10.0
S4	18	6.0	0.9	4.0-7.0
S5	18	8.6	1.2	7.0-11.0
S6	17	22.3	2.0	18.0-25.0
S7	18	8.1	0.9	7.0-10.0

Appendix Table 18b. Nickel (Ni) concentrations in sediments from eight locations within two seasons. Metal concentrations are in mg kg^{-1} (dry weight). n = sample size. S.D. = standard deviation. large = large sampling station area. +*x* days = samples collected *x* days after the other grab and diver samples from the same location.

Season	Sampling Station	Method	n	Mean	S.D.	Range
Pre-monsoon	S1	Grab	10	48.0	2.4	43.0-52.0
Pre-monsoon	S10	Grab	9	25.6	2.5	22.0-30.0
Pre-monsoon	S10	Diver	9	27.0	2.3	24.0-31.0
Pre-monsoon	S2	Grab	9	13.2	2.7	11.0-19.0
Pre-monsoon	S2	Diver	6	12.2	1.7	10.0-15.0
Pre-monsoon	S3	Grab	9	7.1	0.8	6.0-8.0
Pre-monsoon	S4	Grab	9	6.1	0.8	5.0-7.0
Pre-monsoon	S5	Grab	9	9.0	1.5	7.0-11.0
Pre-monsoon	S5	Diver	9	9.6	0.7	9.0-11.0
Pre-monsoon	S6	Grab	8	20.9	1.2	18.0-22.0
Pre-monsoon	S7	Grab	9	8.6	1.0	7.0-10.0
Post-monsoon	S1	Grab	9	44.6	2.1	40.0-47.0
Post-monsoon	S10	Grab	8	25.1	2.3	23.0-30.0
Post-monsoon	S10	Diver	9	24.4	1.9	22.0-28.0
Post-monsoon	S10 (+5 days)	Grab	9	25.2	2.5	22.0-29.0
Post-monsoon	S10 (large)	Grab	9	33.8	5.8	24.0-41.0
Post-monsoon	S2	Grab	9	13.9	1.4	12.0-16.0
Post-monsoon	S2	Diver	9	13.7	1.4	12.0-16.0
Post-monsoon	S2 (+6 days)	Grab	9	13.8	1.4	11.0-16.0
Post-monsoon	S3	Grab	9	7.7	1.5	6.0-10.0
Post-monsoon	S4	Grab	9	5.9	1.1	4.0-7.0
Post-monsoon	S5	Grab	9	8.1	0.8	7.0-9.0
Post-monsoon	S5	Diver	9	8.6	1.4	6.0-10.0
Post-monsoon	S6	Grab	9	23.6	1.6	21.0-25.0
Post-monsoon	S7	Grab	9	7.6	0.5	7.0-8.0

Appendix Table 19a. Lead (Pb) concentrations (averaged over two seasons) in sediments from grab samples collected at eight locations. Metal concentrations are in mg kg^{-1} (dry weight). n = sample size. S.D. = standard deviation. Means with the same superscript indicate a significant difference between locations (p<=0.05 by Tukey's Test).

Sampling Station	n	Mean	S.D.	Range
S1	19	14.8^{abcd}	2.7	11.0-24.0
S10	17	10.8^{efg}	1.3	8.0-13.0
S2	18	9.9^{hij}	1.5	8.0-13.0
S3	18	3.1^{aehk}	1.5	0.5-6.0
S4	18	3.7^{bfil}	1.8	1.0-7.0
S5	18	5.9^{c}	1.6	3.0-9.0
S6	17	10.3^{klm}	1.5	8.0-13.0
S7	18	4.2^{dgjm}	1.2	2.0-6.0

Appendix Table 19b. Lead (Pb) concentrations in sediments from eight locations within two seasons. Metal concentrations are in mg kg^{-1} (dry weight). n = sample size. S.D. = standard deviation. large = large sampling station area. +*x* days = samples collected *x* days after the other grab and diver samples from the same location.

Season	Sampling Station	Method	n	Mean	S.D.	Range
Pre-monsoon	S1	Grab	10	15.7	3.4	11.0-24.0
Pre-monsoon	S10	Grab	9	11.2	1.2	9.0-13.0
Pre-monsoon	S10	Diver	9	12.0	1.3	9.0-14.0
Pre-monsoon	S2	Grab	9	10.3	1.8	8.0-13.0
Pre-monsoon	S2	Diver	6	9.3	2.3	7.0-13.0
Pre-monsoon	S3	Grab	9	3.8	1.3	2.0-6.0
Pre-monsoon	S4	Grab	9	4.3	1.8	1.0-7.0
Pre-monsoon	S5	Grab	9	6.1	1.7	4.0-9.0
Pre-monsoon	S5	Diver	9	5.2	1.3	4.0-7.0
Pre-monsoon	S6	Grab	8	10.1	1.2	8.0-12.0
Pre-monsoon	S7	Grab	9	4.7	0.9	3.0-6.0
Post-monsoon	S1	Grab	9	13.8	1.2	12.0-16.0
Post-monsoon	S10	Grab	8	10.3	1.3	8.0-12.0
Post-monsoon	S10	Diver	9	10.0	1.1	8.0-11.0
Post-monsoon	S10 (+5 days)	Grab	9	10.7	1.1	9.0-12.0
Post-monsoon	S10 (large)	Grab	9	23.0	9.0	14.0-36.0
Post-monsoon	S2	Grab	9	9.4	0.9	8.0-11.0
Post-monsoon	S2	Diver	9	9.4	0.9	8.0-11.0
Post-monsoon	S2 (+6 days)	Grab	9	8.8	1.2	7.0-11.0
Post-monsoon	S3	Grab	9	2.4	1.4	0.5-4.0
Post-monsoon	S4	Grab	9	3.0	1.7	1.0-6.0
Post-monsoon	S5	Grab	9	5.8	1.6	3.0-8.0
Post-monsoon	S5	Diver	9	4.2	1.9	2.0-7.0
Post-monsoon	S6	Grab	9	10.4	1.7	8.0-13.0
Post-monsoon	S7	Grab	9	3.7	1.2	2.0-5.0

Appendix Table 20a. Selenium (Se) concentrations (averaged over two seasons) in sediments from grab samples collected at eight locations. Metal concentrations are in mg kg^{-1} (dry weight). n = sample size. S.D. = standard deviation.

Sampling Station	n	Mean	S.D.	Range
S1	19	0.133	0.193	<0.10-0.74
S10	17	0.172	0.052	<0.10-0.24
S2	18	0.179	0.066	<0.10-0.30
S3	18	0.243	0.051	0.16-0.40
S4	18	0.207	0.044	0.13-0.27
S5	18	0.161	0.072	<0.10-0.29
S6	17	0.172	0.078	<0.10-0.25
S7	18	0.184	0.054	<0.10-0.28

Appendix Table 20b. Selenium (Se) concentrations in sediments from eight locations within two seasons. Metal concentrations are in mg kg^{-1} (dry weight). n = sample size. S.D. = standard deviation. large = large sampling station area. +*x* days = samples collected *x* days after the other grab and diver samples from the same location.

Season	Sampling Station	Method	n	Mean	S.D.	Range
Pre-monsoon	S1	Grab	10	0.202	0.250	<0.10-0.74
Pre-monsoon	S10	Grab	9	0.199	0.042	0.10-0.24
Pre-monsoon	S10	Diver	9	0.167	0.084	<0.10-0.27
Pre-monsoon	S2	Grab	9	0.199	0.070	0.10-0.30
Pre-monsoon	S2	Diver	6	0.192	0.038	0.15-0.25
Pre-monsoon	S3	Grab	9	0.220	0.030	0.16-0.27
Pre-monsoon	S4	Grab	9	0.184	0.039	0.13-0.24
Pre-monsoon	S5	Grab	9	0.127	0.069	<0.10-0.24
Pre-monsoon	S5	Diver	9	0.154	0.024	0.12-0.18
Pre-monsoon	S6	Grab	8	0.223	0.052	0.10-0.25
Pre-monsoon	S7	Grab	9	0.153	0.049	<0.10-0.24
Post-monsoon	S1	Grab	9	0.056	0.017	<0.10-0.10
Post-monsoon	S10	Grab	8	0.143	0.048	<0.10-0.20
Post-monsoon	S10	Diver	9	0.113	0.026	<0.10-0.14
Post-monsoon	S10 (+5 days)	Grab	9	0.138	0.044	0.10-0.24
Post-monsoon	S10 (large)	Grab	9	0.156	0.051	<0.10-0.20
Post-monsoon	S2	Grab	9	0.160	0.060	<0.10-0.27
Post-monsoon	S2	Diver	9	0.191	0.027	0.15-0.23
Post-monsoon	S2 (+6 days)	Grab	9	0.158	0.052	0.11-0.25
Post-monsoon	S3	Grab	9	0.267	0.058	0.22-0.40
Post-monsoon	S4	Grab	9	0.229	0.038	0.15-0.27
Post-monsoon	S5	Grab	9	0.194	0.060	0.10-0.29
Post-monsoon	S5	Diver	9	0.114	0.014	0.09-0.13
Post-monsoon	S6	Grab	9	0.128	0.070	<0.10-0.21
Post-monsoon	S7	Grab	9	0.214	0.042	0.16-0.28

Appendix Table 21a. Silica (Si) concentrations (averaged over two seasons) in sediments from grab samples collected at eight locations. Metal concentrations are in mg kg^{-1} (dry weight). n = sample size. S.D. = standard deviation. Concentrations at all locations were significantly different ($p<=0.05$ by Tukey's Test) to each other except for S3 & S4, S3 & S7, and S4 & S7.

Sampling Station	n	Mean	S.D.	Range
S1	19	29.18	0.36	28.2-29.8
S10	17	17.87	0.42	17.4-18.9
S2	18	8.84	1.38	6.8-11.7
S3	18	4.30	0.67	3.5-6.0
S4	18	3.68	0.33	3.2-4.5
S5	18	5.24	0.25	4.8-5.7
S6	17	13.17	1.22	11.2-15.6
S7	18	3.81	0.35	3.1-4.6

Appendix Table 21b. Silica (Si) concentrations in sediments from eight locations within two seasons. Metal concentrations are in mg kg^{-1} (dry weight). n = sample size. S.D. = standard deviation. large = large sampling station area. +*x* days = samples collected *x* days after the other grab and diver samples from the same location.

Season	Sampling Station	Method	n	Mean	S.D.	Range
Pre-monsoon	S1	Grab	10	29.04	0.45	28.2-29.8
Pre-monsoon	S10	Grab	9	17.96	0.53	17.4-18.9
Pre-monsoon	S10	Diver	9	17.51	0.54	16.6-18.2
Pre-monsoon	S2	Grab	9	8.32	1.75	6.8-11.7
Pre-monsoon	S2	Diver	6	8.54	0.75	7.8-9.7
Pre-monsoon	S3	Grab	9	3.86	0.30	3.5-4.4
Pre-monsoon	S4	Grab	9	3.52	0.39	3.2-4.5
Pre-monsoon	S5	Grab	9	5.17	0.28	4.8-5.6
Pre-monsoon	S5	Diver	9	5.56	0.17	5.31-5.77
Pre-monsoon	S6	Grab	8	12.67	1.13	11.2-15.0
Pre-monsoon	S7	Grab	9	3.77	0.42	3.1-4.6
Post-monsoon	S1	Grab	9	29.33	0.11	29.1-29.5
Post-monsoon	S10	Grab	8	17.76	0.25	17.5-18.3
Post-monsoon	S10	Diver	9	17.98	0.42	17.5-18.8
Post-monsoon	S10 (+5 days)	Grab	9	17.58	0.49	17.0-18.5
Post-monsoon	S10 (large)	Grab	9	15.56	2.22	13.5-18.8
Post-monsoon	S2	Grab	9	9.35	0.63	8.2-10.4
Post-monsoon	S2	Diver	9	8.91	0.98	7.5-11.0
Post-monsoon	S2 (+6 days)	Grab	9	10.40	0.73	9.1-11.6
Post-monsoon	S3	Grab	9	4.74	0.65	4.0-6.0
Post-monsoon	S4	Grab	9	3.84	0.14	3.7-4.1
Post-monsoon	S5	Grab	9	5.31	0.20	5.1-5.7
Post-monsoon	S5	Diver	9	5.31	0.22	5.1-5.6
Post-monsoon	S6	Grab	9	13.62	1.17	11.7-15.6
Post-monsoon	S7	Grab	9	3.86	0.27	3.6-4.5

Appendix Table 22a. Zinc (Zn) concentrations (averaged over two seasons) in sediments from grab samples collected at eight locations. Metal concentrations are in mg kg^{-1} (dry weight). n = sample size. S.D. = standard deviation. Concentrations at all locations were significantly different ($p<=0.05$ by Tukey's Test) to each other except for S10 & S6, and S3 & S7.

Sampling Station	n	Mean	S.D.	Range
S1	19	94.2	3.9	88.0-105.0
S10	17	46.6	1.1	44.0-49.0
S2	18	19.6	4.3	15.0-35.0
S3	18	5.3	1.1	3.0-7.0
S4	18	3.9	0.9	2.0-6.0
S5	18	9.5	0.9	8.0-11.0
S6	17	38.6	1.7	35.0-42.0
S7	18	6.7	1.1	4.0-8.0

Appendix Table 22b. Zinc (Zn) concentrations in sediments from eight locations within two seasons. Metal concentrations are in mg kg^{-1} (dry weight). n = sample size. S.D. = standard deviation. large = large sampling station area. +*x* days = samples collected *x* days after the other grab and diver samples from the same location.

Season	Sampling Station	Method	n	Mean	S.D.	Range
Pre-monsoon	S1	Grab	10	95.8	4.5	91.0-105.0
Pre-monsoon	S10	Grab	9	47.0	1.1	45.0-49.0
Pre-monsoon	S10	Diver	9	46.7	1.5	45.0-49.0
Pre-monsoon	S2	Grab	9	20.1	5.9	15.0-35.0
Pre-monsoon	S2	Diver	6	17.7	1.9	16.0-21.0
Pre-monsoon	S3	Grab	9	5.3	1.2	3.0-7.0
Pre-monsoon	S4	Grab	9	3.9	1.2	2.0-6.0
Pre-monsoon	S5	Grab	9	9.9	0.6	9.0-11.0
Pre-monsoon	S5	Diver	9	9.2	0.7	8.0-10.0
Pre-monsoon	S6	Grab	8	38.1	1.2	36.0-40.0
Pre-monsoon	S7	Grab	9	7.0	0.9	6.0-8.0
Post-monsoon	S1	Grab	9	92.3	2.3	88.0-95.0
Post-monsoon	S10	Grab	8	46.1	1.0	44.0-47.0
Post-monsoon	S10	Diver	9	46.3	1.5	44.0-48.0
Post-monsoon	S10 (+5 days)	Grab	9	45.0	0.9	44.0-46.0
Post-monsoon	S10 (large)	Grab	9	53.7	6.8	45.0-62.0
Post-monsoon	S2	Grab	9	19.0	1.7	16.0-22.0
Post-monsoon	S2	Diver	9	18.9	1.4	17.0-21.0
Post-monsoon	S2 (+6 days)	Grab	9	20.8	2.0	17.0-23.0
Post-monsoon	S3	Grab	9	5.3	1.0	4.0-7.0
Post-monsoon	S4	Grab	9	3.9	0.6	3.0-5.0
Post-monsoon	S5	Grab	9	9.1	0.9	8.0-11.0
Post-monsoon	S5	Diver	9	8.9	0.9	8.0-11.0
Post-monsoon	S6	Grab	9	39.1	2.0	35.0-42.0
Post-monsoon	S7	Grab	9	6.4	1.3	4.0-8.0

Appendix Table 23. Analysis of Variance for differences in transformed metal concentration ($\log_e$(concentration+1)) in the leaf tissue of the seagrass *T. hemprichii* from Campbell Island and Dungeness Reef within two seasons.

Metal	Source of variation	DF	MS	F-ratio	Significance
As	Season	1	0.004	0.010	p=0.924
	Station	1	0.000	0.000	p=0.991
	Season*Station	1	0.100	0.234	p=0.641
	Site{season*station}	8	0.428		
Cd	Season	1	0.394	1.545	p=0.249
	Station	1	0.168	0.657	p=0.441
	Season*Station	1	1.108	4.344	p=0.071
	Site{season*station}	8	0.255		
Co	Season	1	0.039	2.759	p=0.135
	Station	1	0.287	20.489	p=0.002
	Season*Station	1	0.087	6.238	p=0.037
	Site{season*station}	8	0.014		
Cr	Season	1	4.085	11.908	p=0.009
	Station	1	0.331	0.964	p=0.355
	Season*Station	1	0.094	0.273	p=0.615
	Site{season*station}	8	0.343		
Cu	Season	1	1.040	3.809	p=0.087
	Station	1	0.963	3.528	p=0.097
	Season*Station	1	1.150	4.211	p=0.074
	Site{season*station}	8	0.273		
Ni	Season	1	0.014	0.165	p=0.695
	Station	1	0.456	5.567	p=0.046
	Season*Station	1	0.302	3.679	p=0.091
	Site{season*station}	8	0.082		
Pb	Season	1	0.139	2.351	p=0.164
	Station	1	0.006	0.096	p=0.765
	Season*Station	1	0.181	3.068	p=0.118
	Site{season*station}	8	0.059		
Se	Season	1	0.023	0.429	p=0.531
	Station	1	0.020	0.378	p=0.556
	Season*Station	1	0.003	0.055	p=0.820
	Site{season*station}	8	0.053		
Zn	Season	1	0.951	3.961	p=0.082
	Station	1	0.890	3.708	p=0.090
	Season*Station	1	1.227	5.111	p=0.054
	Site{season*station}	8	0.240		

Appendix Table 24. Analysis of Variance for differences in transformed (log_e(concentration+1)) metal concentration in the leaf tissue of the seagrass *T. hemprichii* from Campbell Island, Dungeness Reef and Kokope Reef during the post-monsoon season.

Metal	Source of variation	DF	MS	F-ratio	Significance
As	Station	2	0.209	0.627	p=0.566
	Site{station}	6	0.334		
Cd	Station	2	0.139	1.380	p=0.321
	Site{station}	6	0.100		
Co	Station	2	0.189	36.148	p<0.001
	Site{station}	6	0.005		
Cr	Station	2	0.034	1.054	p=0.405
	Site{station}	6	0.032		
Cu	Station	2	0.053	0.433	p=0.668
	Site{station}	6	0.123		
Fe	Station	2	1.015	3.202	p=0.113
	Site{station}	6	0.317		
Mn	Station	2	0.701	13.949	p=0.006
	Site{station}	6	0.050		
Ni	Station	2	0.039	2.099	p=0.204
	Site{station}	6	0.018		
Pb	Station	2	0.260	38.972	p<0.001
	Site{station}	6	0.007		
Se	Station	2	0.007	4.384	p=0.067
	Site{station}	6	0.002		
Zn	Station	2	0.511	15.990	p=0.004
	Site{station}	6	0.032		

Appendix Table 25. Arsenic (As) concentrations in the leaf tissue of the seagrass *T. hemprichii* from three locations within two seasons. Metal concentrations are in mg kg^{-1} (dry weight). n = sample size. S.D. = standard deviation.

Season	Sampling Station	n	Mean	S.D.	Range
Pre-monsoon	Campbell Is	15	1.53	0.30	1.1-2.0
Pre-monsoon	Dungeness Rf	11	2.00	0.80	1.2-4.0
Post-monsoon	Campbell Is	16	1.71	0.49	1.1-2.8
Post-monsoon	Dungeness Rf	15	1.48	0.22	1.2-1.9
Post-monsoon	Kokope Rf	15	2.45	1.84	1.2-6.8

Appendix Table 26. Cadmium (Cd) concentrations in the leaf tissue of the seagrass *T. hemprichii* from three locations within two seasons. Metal concentrations are in mg kg^{-1} (dry weight). n = sample size. S.D. = standard deviation.

Season	Sampling Station	n	Mean	S.D.	Range
Pre-monsoon	Campbell Is	15	1.77	0.54	0.90-3.0
Pre-monsoon	Dungeness Rf	11	0.80	0.08	0.67-0.94
Post-monsoon	Campbell Is	16	0.71	0.21	0.40-1.23
Post-monsoon	Dungeness Rf	15	1.05	0.19	0.67-1.40
Post-monsoon	Kokope Rf	15	0.78	0.30	0.37-1.20

Appendix Table 27. Cobalt (Co) concentrations in the leaf tissue of the seagrass *T. hemprichii* from three locations within two seasons. Metal concentrations are in mg kg^{-1} (dry weight). n = sample size. S.D. = standard deviation. Means with the same superscript indicate a significant difference between locations ($p<=0.05$ by Tukey's Test).

Season	Sampling Station	n	Mean	S.D.	Range
Pre-monsoon	Campbell Is	15	0.035	0.015	0.01-0.06
Pre-monsoon	Dungeness Rf	11	0.297	0.073	0.14-0.40
Post-monsoon	Campbell Is	16	0.065^{a}	0.037	0.01-0.13
Post-monsoon	Dungeness Rf	15	0.137^{b}	0.069	0.07-0.36
Post-monsoon	Kokope Rf	15	0.323^{ab}	0.086	0.14-0.50

Appendix Table 28. Chromium (Cr) concentrations in the leaf tissue of the seagrass *T. hemprichii* from three locations within two seasons. Metal concentrations are in mg kg^{-1} (dry weight). n = sample size. S.D. = standard deviation.

Season	**Sampling Station**	**n**	**Mean**	**S.D.**	**Range**
Pre-monsoon	Campbell Is	15	1.21	0.60	0.50-3.1
Pre-monsoon	Dungeness Rf	11	1.91	0.64	1.20-3.2
Post-monsoon	Campbell Is	16	0.37	0.31	0.25-1.4
Post-monsoon	Dungeness Rf	15	0.46	0.19	0.25-0.8
Post-monsoon	Kokope Rf	15	0.48	0.24	0.25-0.9

Appendix Table 29. Copper (Cu) concentrations in the leaf tissue of the seagrass *T. hemprichii* from three locations within two seasons. Metal concentrations are in mg kg^{-1} (dry weight). n = sample size. S.D. = standard deviation.

Season	**Sampling Station**	**n**	**Mean**	**S.D.**	**Range**
Pre-monsoon	Campbell Is	15	9.44	1.51	7.2-13.3
Pre-monsoon	Dungeness Rf	31	4.83	0.30	4.4-5.2
Post-monsoon	Campbell Is	16	4.84	1.12	2.9-6.9
Post-monsoon	Dungeness Rf	15	5.00	0.63	4.0-6.4
Post-monsoon	Kokope Rf	15	5.61	1.16	4.0-7.2

Appendix Table 30. Iron (Fe) concentrations in the leaf tissue of the seagrass *T. hemprichii* from three locations within two seasons. Metal concentrations are in mg kg^{-1} (dry weight). n = sample size. S.D. = standard deviation. nd = not determined.

Season	**Sampling Station**	**n**	**Mean**	**S.D.**	**Range**
Pre-monsoon	Campbell Is	15	nd		
Pre-monsoon	Dungeness Rf	11	nd		
Post-monsoon	Campbell Is	16	101.8	37.5	75-236
Post-monsoon	Dungeness Rf	15	126.3	15.2	100-151
Post-monsoon	Kokope Rf	15	175.6	75.2	109-341

Appendix Table 31. Manganese (Mn) concentrations in the leaf tissue of the seagrass *T. hemprichii* from three locations within two seasons. Metal concentrations are in mg kg^{-1} (dry weight). n = sample size. S.D. = standard deviation. nd = not determined. Means with the same superscript indicate a significant difference between locations (p<=0.05 by Tukey's Test).

Season	Sampling Station	n	Mean	S.D.	Range
Pre-monsoon	Campbell Is	15	nd		
Pre-monsoon	Dungeness Rf	11	nd		
Post-monsoon	Campbell Is	16	21.5^{ab}	2.0	18-25
Post-monsoon	Dungeness Rf	15	28.2^{a}	3.3	23-33
Post-monsoon	Kokope Rf	15	33.6^{b}	3.9	28-41

Appendix Table 32. Nickel (Ni) concentrations in the leaf tissue of the seagrass *T. hemprichii* from three locations within two seasons. Metal concentrations are in mg kg^{-1} (dry weight). n = sample size. S.D. = standard deviation.

Season	Sampling Station	n	Mean	S.D.	Range
Pre-monsoon	Campbell Is	15	2.05	0.43	1.2-2.7
Pre-monsoon	Dungeness Rf	11	3.20	0.43	2.7-4.3
Post-monsoon	Campbell Is	16	2.65	0.32	2.2-3.3
Post-monsoon	Dungeness Rf	15	2.77	0.44	2.2-3.7
Post-monsoon	Kokope Rf	15	3.02	0.43	2.2-3.8

Appendix Table 33. Lead (Pb) concentrations in the leaf tissue of the seagrass *T. hemprichii* from three locations within two seasons. Metal concentrations are in mg kg^{-1} (dry weight). n = sample size. S.D. = standard deviation. Means with the same superscript indicate a significant difference between locations (p<=0.05 by Tukey's Test).

Season	Sampling Station	n	Mean	S.D.	Range
Pre-monsoon	Campbell Is	15	0.300	0.173	0.10-0.60
Pre-monsoon	Dungeness Rf	11	0.495	0.118	0.36-0.70
Post-monsoon	Campbell Is	16	0.314^{ab}	0.115	0.15-0.56
Post-monsoon	Dungeness Rf	15	0.190^{ac}	0.068	0.10-0.35
Post-monsoon	Kokope Rf	15	0.555^{bc}	0.219	0.26-0.95

Appendix Table 34. Selenium (Se) concentrations in the leaf tissue of the seagrass *T. hemprichii* from three locations within two seasons. Metal concentrations are in mg kg^{-1} (dry weight). n = sample size. S.D. = standard deviation. bdl = below detection limit (<0.10).

Season	**Sampling n**	**Mean**	**S.D.**	**Range**	**Station**
Pre-monsoon	Campbell Is	15	0.103	0.085	0.05-0.35
Pre-monsoon	Dungeness Rf	11	0.205	0.232	0.05-0.80
Post-monsoon	Campbell Is	16	0.072	0.052	0.05-0.20
Post-monsoon	Dungeness Rf	15	0.100	0.067	0.05-0.30
Post-monsoon	Kokope Rf	15	bdl		

Appendix Table 35. Zinc (Zn) concentrations in the leaf tissue of the seagrass *T. hemprichii* from three locations within two seasons. Metal concentrations are in mg kg^{-1} (dry weight). n = sample size. S.D. = standard deviation. Means with the same superscript indicate a significant difference between locations ($p<=0.05$ by Tukey's Test).

Season	**Sampling Station**	**n**	**Mean**	**S.D.**	**Range**
Pre-monsoon	Campbell Is	12	7.55	2.27	3.3-12.0
Pre-monsoon	Dungeness Rf	8	3.69	0.29	3.4-4.3
Post-monsoon	Campbell Is	16	3.60^{a}	0.67	2.8-5.1
Post-monsoon	Dungeness Rf	15	3.94^{b}	0.63	3.2-5.3
Post-monsoon	Kokope Rf	15	5.76^{ab}	1.04	4.0-7.5

Appendix Table 36. Analysis of Variance for differences in transformed (log_e(concentration+1)) metal concentration in the leaf tissue of the seagrass *T. ciliatum* from Dungeness and Kokope Reefs during the pre-monsoon season.

Metal	Source of variation	DF	MS	F-ratio	Significance
As	Station	1	0.293	41.098	p=0.023
	Site{station}	2	0.007		
Cd	Station	1	0.010	29.037	p=0.033
	Site{station}	2	0.000		
Co	Station	1	0.000	0.002	p=0.967
	Site{station}	2	0.004		
Cr	Station	1	0.202	16.422	p=0.056
	Site{station}	2	0.012		
Cu	Station	1	0.000	0.001	p=0.977
	Site{station}	2	0.102		
Ni	Station	1	0.483	6.147	p=0.131
	Site{station}	2	0.079		
Pb	Station	1	0.587	44.215	p=0.022
	Site{station}	2	0.013		
Se	Station	1	0.001	0.118	p=0.764
	Site{station}	2	0.012		
Zn	Station	1	0.659	48.218	p=0.020
	Site{station}	2	0.014		

Appendix Table 37. Trace metal concentrations in the leaf tissue of the seagrass *T. ciliatum* from two locations during the pre-monsoon season. Metal concentrations are in mg kg^{-1} (dry weight). n = sample size. S.D. = standard deviation. na = not analysed

Metal	Sampling Station	n	Mean	S.D.	Range
As	Dungeness Rf	10	1.12	0.19	0.8-1.5
	Kokope Rf	5	0.56	0.17	0.4-0.8
Cd	Dungeness Rf	10	0.98	0.09	0.83-1.1
	Kokope Rf	5	0.88	0.13	0.67-0.99
Co	Dungeness Rf	10	0.26	0.07	0.15-0.40
	Kokope Rf	5	0.26	0.08	0.17-0.38
Cr	Dungeness Rf	10	1.26	0.47	0.7-2.4
	Kokope Rf	5	0.76	0.42	0.5-1.5
Cu	Dungeness Rf	10	7.51	1.43	5.9-10.1
	Kokope Rf	5	7.70	0.44	7.0-8.2
Fe	Dungeness Rf	10	180.1	59.7	14-328
	Kokope Rf	5	na		
Hg	Dungeness Rf	10	<0.05		
	Kokope Rf	5	<0.05		
Mn	Dungeness Rf	10	38.0	2.2	34.0-41.0
	Kokope Rf	5	na		
Ni	Dungeness Rf	10	2.90	0.69	2.0-4.0
	Kokope Rf	5	1.74	0.65	1.1-2.8
Pb	Dungeness Rf	10	0.43	0.21	0.18-0.88
	Kokope Rf	5	1.20	0.57	0.3-1.7
Se	Dungeness Rf	10	0.11	0.07	<0.1-0.2
	Kokope Rf	5	0.11	0.07	<0.1-0.2
Zn	Dungeness Rf	10	4.51	0.57	3.8-5.2
	Kokope Rf	5	7.72	1.39	6.0-9.4

Appendix Table 38. Analysis of Variance for differences in transformed metal concentration ($\log_e$(concentration+1)) in the kidney of the clam *T. crocea* from Aureed Island, Campbell Island, Dungeness Reef and Kokope Reef within two seasons.

Metal	Source of variation	DF	MS	F-ratio	Significance
Ag	Season	1	2.144	2.773	p=0.115
	Station	3	3.396	4.393	p=0.020
	Season*Station	3	0.604	0.781	p=0.522
	Site{season*station}	16	0.773		
Al	Season	1	27.363	3.750	p=0.071
	Station	3	17.528	2.402	p=0.106
	Season*Station	3	1.252	0.172	p=0.914
	Site{season*station}	16	7.296		
As	Season	1	3.633	4.541	p=0.049
	Station	3	0.493	0.617	p=0.614
	Season*Station	3	0.430	0.537	p=0.663
	Site{season*station}	16	0.800		
Cd	Season	1	7.945	4.387	p=0.052
	Station	3	14.073	7.771	p=0.002
	Season*Station	3	3.543	1.956	p=0.161
	Site{season*station}	16	1.811		
Co	Season	1	7.852	8.754	p=0.009
	Station	3	0.048	0.054	p=0.983
	Season*Station	3	0.336	0.375	p=0.773
	Site{season*station}	16	0.897		
Cr	Season	1	1.156	2.694	p=0.120
	Station	3	0.580	1.351	p=0.293
	Season*Station	3	0.134	0.312	p=0.816
	Site{season*station}	16	0.429		
Cu	Season	1	0.024	0.049	p=0.828
	Station	3	2.348	4.811	p=0.014
	Season*Station	3	0.409	0.839	p=0.492
	Site{season*station}	16	0.488		
Fe	Season	1	0.346	0.412	p=0.530
	Station	3	3.977	4.734	p=0.015
	Season*Station	3	2.053	2.444	p=0.102
	Site{season*station}	16	0.840		
Hg	Season	1	1.603	8.016	p=0.012
	Station	3	0.434	2.171	p=0.131
	Season*Station	3	0.086	0.432	p=0.733
	Site (season*station)	16	0.200		

(Appendix Table 38 continued over)

Metal	Source of variation	DF	MS	F-ratio	Significance
Mn	Season	1	17.815	1.215	p=0.287
	Station	3	11.325	0.772	p=0.526
	Season*Station	3	5.371	0.366	p=0.778
	Site{season*station}	16	14.663		
Ni	Season	1	6.682	10.919	p=0.004
	Station	3	3.756	6.137	p=0.006
	Season*Station	3	0.417	0.681	p=0.577
	Site{season*station}	16	0.612		
Pb	Season	1	4.480	5.887	p=0.027
	Station	3	1.045	1.373	p=0.287
	Season*Station	3	0.508	0.667	p=0.584
	Site{season*station}	16	0.761		
Se	Season	1	3.032	6.955	p=0.018
	Station	3	0.107	0.245	p=0.864
	Season*Station	3	0.360	0.827	p=0.498
	Site{season*station}	16	0.436		
Sr	Season	1	0.454	0.761	p=0.396
	Station	3	0.330	0.553	p=0.653
	Season*Station	3	0.187	0.316	p=0.813
	Site{season*station}	16	0.597		
U	Season	1	12.172	16.906	p=0.001
	Station	3	0.362	0.503	p=0.686
	Season*Station	3	0.687	0.954	p=0.438
	Site{season*station}	16	0.720		
Zn	Season	1	3.932	1.625	p=0.221
	Station	3	72.294	29.873	p<0.001
	Season*Station	3	7.721	3.190	p=0.052
	Site{season*station}	16	2.420		

Appendix Table 39a. Silver (Ag) concentrations (mean over two seasons) in the kidney of the clam *T. crocea* from four locations. Metal concentrations are in mg kg^{-1} (dry weight). Means with the same superscript indicate a significant difference among locations (p<=0.05 by Tukey's Test). n = sample size. S.D. = standard deviation.

Sampling Station	n	Mean	S.D.	Range
Aureed Is	59	0.80[a]	3.23	0.01-24.40
Campbell Is	52	1.24	3.47	0.03-22.70
Dungeness Rf	46	1.12	1.60	0.03-6.01
Kokope Rf	50	1.88[a]	1.98	0.16-8.82

Appendix Table 39b. Silver (Ag) concentrations in the kidney of the clam *T. crocea* from four locations within two seasons. Metal concentrations are in mg kg^{-1} (dry weight). Means with the same superscript indicate a significant difference among locations (p<=0.05 by Tukey's Test). n = sample size. S.D. = standard deviation.

Season	Sampling Station	n	Mean	S.D.	Range
Pre-monsoon	Aureed Is	44	1.03	3.72	0.01-24.40
Pre-monsoon	Campbell Is	37	1.60	4.06	0.03-22.70
Pre-monsoon	Dungeness Rf	31	1.45	1.79	0.05-6.01
Pre-monsoon	Kokope Rf	35	1.70	1.87	0.16-8.82
Post-monsoon	Aureed Is	15	0.14	0.24	0.03-1.00
Post-monsoon	Campbell Is	15	0.34	0.50	0.03-1.80
Post-monsoon	Dungeness Rf	15	0.44	0.78	0.03-3.00
Post-monsoon	Kokope Rf	15	2.29	2.23	0.26-6.40

Appendix Table 40. Aluminium (Al) concentrations in the kidney of the clam *T. crocea* from four locations within two seasons. Metal concentrations are in mg kg^{-1} (dry weight). n = sample size. S.D. = standard deviation.

Season	Sampling Station	n	Mean	S.D.	Range
Pre-monsoon	Aureed Is	44	22.88	21.83	5.7-112.0
Pre-monsoon	Campbell Is	37	49.41	55.51	3.9-276.0
Pre-monsoon	Dungeness Rf	31	83.54	105.37	6.4-562.0
Pre-monsoon	Kokope Rf	35	166.45	173.21	5.1-621.0
Post-monsoon	Aureed Is	15	11.27	7.68	2.7-27.0
Post-monsoon	Campbell Is	15	25.91	30.84	6.3-120.0
Post-monsoon	Dungeness Rf	15	10.83	5.49	4.3-22.0
Post-monsoon	Kokope Rf	15	57.28	42.81	7.2-170.0

Appendix Table 41. Arsenic (As) concentrations in the kidney of the clam *T. crocea* from four locations within two seasons. Metal concentrations are in mg kg^{-1} (dry weight). n = sample size. S.D. = standard deviation.

Season	Sampling Station	n	Mean	S.D.	Range
Pre-monsoon	Aureed Is	36	441.78	144.40	226.0-868.0
Pre-monsoon	Campbell Is	31	520.42	301.47	176.0-1660.0
Pre-monsoon	Dungeness Rf	10	425.90	186.49	174.0-730.0
Pre-monsoon	Kokope Rf	23	340.26	143.85	128.0-696.0
Post-monsoon	Aureed Is	15	564.67	255.28	200.0-1100.0
Post-monsoon	Campbell Is	15	688.67	158.87	430.0-980.0
Post-monsoon	Dungeness Rf	15	561.33	104.26	380.0-780.0
Post-monsoon	Kokope Rf	14	622.14	158.32	270.0-830.0

Appendix Table 42a. Cadmium (Cd) concentrations (mean of two seasons) in the kidney of the clam *T. crocea* from four locations. Metal concentrations are in mg kg^{-1} (dry weight). Means with the same superscript indicate a significant difference among locations (p<=0.05 by Tukey's Test). n = sample size. S.D. = standard deviation.

Sampling Station	n	Mean	S.D.	Range
Aureed Is	59	69.65^{a}	36.21	1.3-172.0
Campbell Is	52	85.17^{b}	48.93	1.6-200.0
Dungeness Rf	46	72.21^{c}	44.96	5.6-180.0
Kokope Rf	50	221.45^{abc}	99.18	63.6-593.6

Appendix Table 42b. Cadmium (Cd) concentrations in the kidney of the clam *T. crocea* from four locations within two seasons. Metal concentrations are in mg kg^{-1} (dry weight). Means with the same superscript indicate a significant difference among locations (p<=0.05 by Tukey's Test). n = sample size. S.D. = standard deviation.

Season	Sampling Station	n	Mean	S.D.	Range
Pre-monsoon	Aureed Is	44	71.94	32.24	1.3-172.0
Pre-monsoon	Campbell Is	37	63.59^{a}	34.06	1.6-137.0
Pre-monsoon	Dungeness Rf	31	49.87^{b}	25.20	5.6-104.0
Pre-monsoon	Kokope Rf	35	199.79^{ab}	100.24	63.6-593.0
Post-monsoon	Aureed Is	15	62.93^{c}	46.63	10.0-160.0
Post-monsoon	Campbell Is	15	138.40	38.36	77.0-200.0
Post-monsoon	Dungeness Rf	15	118.40	41.78	15.0-180.0
Post-monsoon	Kokope Rf	15	272.00^{c}	78.21	110.0-420.0

Appendix Table 43. Cobalt (Co) concentrations in the kidney tissue of the clam *T. crocea* from four locations within two seasons. Metal concentrations are in mg kg^{-1} (dry weight). n = sample size. S.D. = standard deviation.

Season	Sampling Station	n	Mean	S.D.	Range
Pre-monsoon	Aureed Is	36	120.11	27.07	79.6-176.0
Pre-monsoon	Campbell Is	31	110.01	33.63	55.8-201.0
Pre-monsoon	Dungeness Rf	10	88.47	49.51	28.3-160.0
Pre-monsoon	Kokope Rf	23	101.93	42.58	31.3-208.0
Post-monsoon	Aureed Is	15	156.67	34.57	100.0-210.0
Post-monsoon	Campbell Is	15	186.67	43.37	110.0-260.0
Post-monsoon	Dungeness Rf	15	171.33	55.02	100.0-320.0
Post-monsoon	Kokope Rf	14	192.00	50.05	58.0-260.0

Appendix Table 44. Chromium (Cr) concentrations in the kidney tissue of the clam *T. crocea* from four locations within two seasons. Metal concentrations are in mg kg^{1} (dry weight). n = sample size. S.D. = standard deviation.

Season	Sampling Station	n	Mean	S.D.	Range
Pre-monsoon	Aureed Is	44	4.30	1.35	1.42-8.16
Pre-monsoon	Campbell Is	37	3.75	1.52	1.51-7.43
Pre-monsoon	Dungeness Rf	31	3.73	1.26	1.72-6.77
Pre-monsoon	Kokope Rf	35	3.06	1.47	1.16-7.80
Post-monsoon	Aureed Is	15	4.45	1.25	2.70-6.60
Post-monsoon	Campbell Is	15	5.51	2.40	2.80-13.00
Post-monsoon	Dungeness Rf	15	4.96	2.20	2.70-10.00
Post-monsoon	Kokope Rf	15	3.46	0.78	2.40-4.90

Appendix Table 45a. Copper (Cu) concentrations (mean of two seasons) in the kidney tissue of the clam *T. crocea* from four locations. Metal concentrations are in mg kg^{-1} (dry weight). Means with the same superscript indicate a significant difference among locations (p<=0.05 by Tukey's Test). n = sample size. S.D. = standard deviation.

Sampling Station	n	Mean	S.D.	Range
Aureed Is	59	2.78	0.68	1.20-4.41
Campbell Is	52	4.60^{a}	3.18	2.20-23.20
Dungeness Rf	46	2.38^{a}	0.67	1.30-3.86
Kokope Rf	50	4.91	8.33	1.60-62.00

Appendix Table 45b. Copper (Cu) concentrations in the kidney of the clam *T. crocea* from four locations within two seasons. Metal concentrations are in mg^{-1} (dry weight).Means with the same superscript indicate a significant difference among locations (p<=0.05 by Tukey's Test).n= sample size, S.D. = standard deviation

Season	Sampling Station	n	Mean	S.D.	Range
Pre-monsoon	Aureed Is	44	2.98	0.57	1.89-4.41
Pre-monsoon	Campbell Is	37	4.38	3.55	2.20-23.20
Pre-monsoon	Dungeness Rf	31	2.53	0.67	1.34-3.86
Pre-monsoon	Kokope Rf	35	3.85	1.28	2.06-9.22
Post-monsoon	Aureed Is	15	2.21	0.64	1.20-3.70
Post-monsoon	Campbell Is	15	5.13	1.99	2.50-8.90
Post-monsoon	Dungeness Rf	15	2.07	0.57	1.30-3.30
Post-monsoon	Kokope Rf	15	7.38	15.15	1.60-62.00

Appendix Table 46a. Iron (Fe) concentrations (mean of two seasons) in the kidney tissue of the clam *T. crocea* from four locations. Metal concentrations are in mg kg^{-1} (dry weight). Means with the same superscript indicate a significant difference among locations (p<=0.05 by Tukey's Test). n = sample size. S.D. = standard deviation.

Sampling Station	n	Mean	S.D.	Range
Aureed Is	59	1113.6^{a}	408.5	507.0-2450.0
Campbell Is	52	1078.1^{b}	472.2	392.0-2720.0
Dungeness Rf	46	2654.6^{ab}	1468.7	568.0-6040.0
Kokope Rf	50	1289.5	548.9	479.0-2800.0

Appendix Table 46b. Iron (Fe) concentrations in the kidney tissue of the clam *T. crocea* from four locations within two seasons. Metal concentrations are in mg kg^{-1} (dry weight). Means with the same superscript indicate a significant difference among locations (p<=0.05 by Tukey's Test). n = sample size. S.D. = standard deviation.

Season	Sampling Station	n	Mean	S.D.	Range
Pre-monsoon	Aureed Is	44	1068.2	418.8	507.0-2450.0
Pre-monsoon	Campbell Is	37	965.5	460.7	392.0-2720.0
Pre-monsoon	Dungeness Rf	31	3143.6	1532.8	568.0-6040.0
Pre-monsoon	Kokope Rf	35	1159.3	502.8	479.0-2400.0
Post-monsoon	Aureed Is	15	1246.7	356.5	870.0-2100.0
Post-monsoon	Campbell Is	15	1356.0	387.7	790.0-1900.0
Post-monsoon	Dungeness Rf	15	1644.0	524.4	960.0-3200.0
Post-monsoon	Kokope Rf	15	1593.3	547.0	1100.0-2800.0

Appendix Table 47. Mercury (Hg) concentrations in the kidney tissue of the clam *T. crocea* from four locations within two seasons. Metal concentrations are in mg kg^{-1} (dry weight). n = sample size. S.D. = standard deviation.

Season	Sampling Station	n	Mean	S.D.	Range
Pre-monsoon	Aureed Is	44	1.54	0.33	0.83-2.44
Pre-monsoon	Campbell Is	37	1.66	0.57	0.63-3.20
Pre-monsoon	Dungeness Rf	31	0.86	0.31	0.27-1.42
Pre-monsoon	Kokope Rf	35	1.37	0.48	0.71-2.74
Post-monsoon	Aureed Is	15	0.93	0.34	0.42-1.50
Post-monsoon	Campbell Is	15	0.99	0.25	0.66-1.50
Post-monsoon	Dungeness Rf	15	0.72	0.20	0.37-0.95
Post-monsoon	Kokope Rf	15	1.02	0.39	0.31-1.60

Appendix Table 48. Manganese (Mn) concentrations in the kidney tissue of the clam *T. crocea* from four locations within two seasons. Metal concentrations are in mg kg^{-1} (dry weight). n = sample size. S.D. = standard deviation.

Season	Sampling Station	n	Mean	S.D.	Range
Pre-monsoon	Aureed Is	36	12516.7	3252.1	8000.0-22000.0
Pre-monsoon	Campbell Is	31	12467.7	5961.8	7100.0-36000.0
Pre-monsoon	Dungeness Rf	10	5333.2	4482.3	32.0-13000.0
Pre-monsoon	Kokope Rf	23	17743.5	9484.8	5800.0-48000.0
Post-monsoon	Aureed Is	15	14233.3	3353.4	9500.0-21000.0
Post-monsoon	Campbell Is	15	16720.0	3622.0	9800.0-21000.0
Post-monsoon	Dungeness Rf	15	11026.7	2785.8	6700.0-17000.0
Post-monsoon	Kokope Rf	14	22000.0	5697.5	8000.0-31000.0

Appendix Table 49a. Nickel (Ni) concentrations (mean of two seasons) in the kidney tissue of the clam *T. crocea* from four locations. Metal concentrations are in mg kg^{-1} (dry weight). Means with the same superscript indicate a significant difference among locations ($p<=0.05$ by Tukey's Test). n = sample size. S.D. = standard deviation.

Sampling Station	n	Mean	S.D.	Range
Aureed Is	51	1241.5^{a}	337.6	703.0-2400.0
Campbell Is	46	994.3	381.1	457.0-2300.0
Dungeness Rf	25	905.5	489.7	227.0-2100.0
Kokope Rf	37	624.7^{a}	292.0	156.0-1200.0

Appendix Table 49b. Nickel (Ni) concentrations in the kidney tissue of the clam *T. crocea* from four locations within two seasons. Metal concentrations are in mg kg^{-1} (dry weight). Means with the same superscript indicate a significant difference among locations ($p<=0.05$ by Tukey's Test). n = sample size. S.D. = standard deviation.

Season	Sampling Station	n	Mean	S.D.	Range
Pre-monsoon	Aureed Is	36	1164.4	286.0	703.0-1690.0
Pre-monsoon	Campbell Is	31	843.8	272.9	457.0-1590.0
Pre-monsoon	Dungeness Rf	10	628.7	446.5	227.0-1640.0
Pre-monsoon	Kokope Rf	23	466.7	186.1	156.0-930.0
Post-monsoon	Aureed Is	15	1426.7	388.2	1000.0-2400.0
Post-monsoon	Campbell Is	15	1305.3	391.5	690.0-2300.0
Post-monsoon	Dungeness Rf	15	1090.0	437.9	650.0-2100.0
Post-monsoon	Kokope Rf	14	884.3	246.7	270.0-1200.0

Appendix Table 50. Lead (Pb) concentrations in the kidney tissue of the clam *T. crocea* from four locations within two seasons. Metal concentrations are in mg kg^{-1} (dry weight). n = sample size. S.D. = standard deviation.

Season	Sampling Station	n	Mean	S.D.	Range
Pre-monsoon	Aureed Is	36	22.41	7.94	12.1-47.0
Pre-monsoon	Campbell Is	31	18.54	5.87	8.7-33.1
Pre-monsoon	Dungeness Rf	10	11.83	8.41	3.3-29.0
Pre-monsoon	Kokope Rf	23	21.38	11.23	6.4-56.3
Post-monsoon	Aureed Is	15	24.46	6.78	9.9-34.0
Post-monsoon	Campbell Is	15	29.47	7.35	17.0-47.0
Post-monsoon	Dungeness Rf	15	18.53	4.44	13.0-25.0
Post-monsoon	Kokope Rf	14	37.36	10.22	17.0-52.0

Appendix Table 51. Selenium (Se) concentrations in the kidney tissue of the clam *T. crocea* from four locations within two seasons. Metal concentrations are in mg kg^{-1} (dry weight). n = sample size. S.D. = standard deviation.

Season	Sampling Station	n	Mean	S.D.	Range
Pre-monsoon	Aureed Is	44	49.29	11.80	26.2-73.8
Pre-monsoon	Campbell Is	37	35.51	6.62	19.8-49.5
Pre-monsoon	Dungeness Rf	31	37.37	11.57	13.7-53.2
Pre-monsoon	Kokope Rf	35	37.07	10.04	15.8-64.4
Post-monsoon	Aureed Is	15	28.00	7.29	20.0-45.0
Post-monsoon	Campbell Is	15	31.27	4.45	20.0-37.0
Post-monsoon	Dungeness Rf	15	29.47	8.06	19.0-48.0
Post-monsoon	Kokope Rf	15	30.33	10.17	18.0-59.0

Appendix Table 52. Strontium (Sr) concentrations in the kidney tissue of the clam *T. crocea* from four locations within two seasons. Metal concentrations are in mg kg^{-1} (dry weight). n = sample size. S.D. = standard deviation.

Season	Sampling Station	n	Mean	S.D.	Range
Pre-monsoon	Aureed Is	44	858.6	153.6	560.0-1200.0
Pre-monsoon	Campbell Is	37	653.0	170.7	290.0-1100.0
Pre-monsoon	Dungeness Rf	31	782.6	227.2	350.0-1300.0
Pre-monsoon	Kokope Rf	35	767.1	197.3	430.0-1200.0
Post-monsoon	Aureed Is	15	823.3	210.4	560.0-1200.0
Post-monsoon	Campbell Is	15	788.0	251.9	430.0-1300.0
Post-monsoon	Dungeness Rf	15	808.7	195.6	460.0-1100.0
Post-monsoon	Kokope Rf	15	1001.3	321.3	550.0-1400.0

Appendix Table 53. Uranium (U) concentrations in the kidney tissue of the clam *T. crocea* from four locations within two seasons. Metal concentrations are in mg kg^{-1} (dry weight). n = sample size. S.D. = standard deviation.

Season	Sampling Station	n	Mean	S.D.	Range
Pre-monsoon	Aureed Is	44	3.50	1.37	1.81-8.18
Pre-monsoon	Campbell Is	37	3.05	1.18	1.36-6.08
Pre-monsoon	Dungeness Rf	31	2.99	1.68	0.64-8.20
Pre-monsoon	Kokope Rf	35	2.58	1.22	0.58-5.82
Post-monsoon	Aureed Is	15	4.50	1.46	1.80-6.70
Post-monsoon	Campbell Is	15	7.61	1.98	4.70-11.00
Post-monsoon	Dungeness Rf	15	6.99	3.47	3.00-16.00
Post-monsoon	Kokope Rf	15	5.75	2.40	2.40-11.00

Appendix Table 54a. Zinc (Zn) concentrations (mean of two seasons) in the kidney tissue of the clam *T. crocea* from four locations. Metal concentrations are in mg kg^{-1} (dry weight). Means with the same superscript indicate a significant difference among locations (p<=0.05 by Tukey's Test). n = sample size. S.D. = standard deviation.

Sampling Station	n	Mean	S.D.	Range
Aureed Is	59	50.04^{ab}	43.44	2.18-170.00
Campbell Is	52	146.60^{acd}	97.80	5.12-430.00
Dungeness Rf	46	22.77^{ace}	26.47	3.06-150.00
Kokope Rf	50	361.92^{bde}	159.34	72.0-760.00

Appendix Table 54b. Zinc (Zn) concentrations in the kidney tissue of the clam *T. crocea* from four locations within two seasons. Metal concentrations are in mg kg^{-1} (dry weight). Means with the same superscript indicate a significant difference among locations (p<=0.05 by Tukey's Test). n = sample size. S.D. = standard deviation.

Season Station	Sampling	n	Mean	S.D.	Range
Pre-monsoon	Aureed Is	44	54.68^{ab}	41.37	2.18-154.00
Pre-monsoon	Campbell Is	37	116.51^{a}	78.11	5.12-274.00
Pre-monsoon	Dungeness Rf	31	13.26^{c}	10.71	3.06-50.00
Pre-monsoon	Kokope Rf	35	324.97^{bc}	128.24	87.00-628.00
Post-monsoon	Aureed Is	15	36.44^{de}	47.93	3.20-170.00
Post-monsoon	Campbell Is	15	220.80^{fg}	104.23	22.00-430.00
Post-monsoon	Dungeness Rf	15	42.41^{dfh}	37.33	4.90-150.00
Post-monsoon	Kokope Rf	15	448.13^{egh}	193.78	72.00-760.00

Appendix Table 55. Analysis of Variance for differences in transformed (log_e(concentration+1)) metal concentration in the kidney of the clam *T. maxima* from Campbell Island within two seasons.

Metal	Source of variation	DF	MS	F-ratio	Significance
Al	Season	1	0.000	0.000	p=0.985
	Site{season}	4	0.910		
As	Season	1	0.088	2.531	p=0.187
	Site{season}	4	0.035		
Cd	Season	1	5.868	5.117	p=0.086
	Site{season}	4	1.147		
Co	Season	1	1.830	18.137	p=0.013
	Site{season}	4	0.101		
Cr	Season	1	0.827	43.383	p=0.003
	Site{season}	4	0.019		
Cu	Season	1	1.075	18.931	p=0.012
	Site{season}	4	0.057		
Fe	Season	1	0.391	8.758	p=0.042
	Site{season}	4	0.045		
Hg	Season	1	0.001	0.031	p=0.869
	Site{season}	4	0.024		
Mn	Season	1	0.407	9.091	p=0.039
	Site{season}	4	0.045		
Ni	Season	1	1.012	6.651	p=0.061
	Site{season}	4	0.152		
Pb	Season	1	0.102	0.780	p=0.427
	Site{season}	4	0.131		
Se	Season	1	0.718	30.683	p=0.005
	Site{season}	4	0.023		
Zn	Season	1	0.920	0.824	p=0.415
	Site{season}	4	1.117		

Appendix Table 56. Analysis of Variance for differences in transformed ($\log_e$ (concentration+1)) metal concentration in the kidney of the clam *T. maxima* from Campbell and Raine Islands during the pre-monsoon season. Raine Is data provided by Barry and Rayment (1992).

Metal	Source of variation	DF	MS	F-ratio	Significance
Al	Station	1	9.912	17.815	p=0.013
	Site{station}	4	0.556		
As	Station	1	1.546	5.029	p=0.088
	Site{station}	4	0.307		
Cd	Station	1	14.287	11.039	p=0.029
	Site{station}	4	1.294		
Co	Station	1	0.001	0.008	p=0.934
	Site{station}	4	0.140		
Cr	Station	1	0.797	12.957	p=0.023
	Site{station}	4	0.062		
Cu	Station	1	0.268	3.925	p=0.119
	Site{station}	4	0.068		
Fe	Station	1	0.673	5.077	p=0.087
	Site{station}	4	0.133		
Hg	Station	1	0.116	10.535	p=0.032
	Site{station}	4	0.011		
Mn	Station	1	2.789	18.615	p=0.013
	Site{station}	4	0.150		
Ni	Station	1	10.657	24.385	p=0.008
	Site{station}	4	0.437		
Pb	Station	1	0.001	0.011	p=0.923
	Site{station}	4	0.067		
Se	Station	1	0.094	1.630	p=0.271
	Site{station}	4	0.058		
Zn	Station	1	12.147	10.936	p=0.030
	Site{station}	4	1.111		

Appendix Table 57. Analysis of Variance for differences in transformed ($\log_e$ (concentration+1)) metal concentration in the kidney of the clam *T. maxima* from Campbell and Aureed Islands within the post-monsoon season.

Metal	Source of variation	DF	MS	F-ratio	Significance
Ag	Station	1	1.306	4.779	p=0.094
	Site{station}	4	0.273		
Al	Station	1	2.661	4.884	p=0.092
	Site{station}	4	0.545		
As	Station	1	0.183	2.467	p=0.191
	Site{station}	4	0.074		
Cd	Station	1	2.427	4.925	p=0.091
	Site{station}	4	0.493		
Co	Station	1	0.394	4.503	p=0.101
	Site{station}	4	0.088		
Cr	Station	1	0.046	2.396	p=0.197
	Site{station}	4	0.019		
Cu	Station	1	3.052	37.435	p=0.004
	Site{station}	4	0.082		
Fe	Station	1	0.102	2.644	p=0.179
	Site{station}	4	0.039		
Hg	Station	1	0.029	1.561	p=0.280
	Site{station}	4	0.019		
Mn	Station	1	0.478	25.217	p=0.007
	Site{station}	4	0.019		
Ni	Station	1	0.356	2.211	p=0.211
	Site{station}	4	0.161		
Pb	Station	1	0.001	0.006	p=0.942
	Site{station}	4	0.114		
Se	Station	1	0.092	3.116	p=0.152
	Site{station}	4	0.030		
Sr	Station	1	0.378	8.763	p=0.042
	Site{station}	4	0.043		
U	Station	1	1.381	126.792	p<0.001
	Site{station}	4	0.011		
Zn	Station	1	6.703	21.221	p=0.010
	Site{station}	4	0.316		

Appendix Table 58. Trace metal concentrations in the kidney of the clam *T. maxima* from different locations within two seasons. Metal concentrations are in mg kg^{-1} (dry weight). n = sample size. nd = not determined.Raine Is data provided by Barry and Rayment (1992).

Metal	**Season**	**Sampling Station**	**n**	**Mean**	**S.D.**	**Range**
Ag	Pre-monsoon	Campbell Is	13	nd		
	Pre-monsoon	Raine Is	21	nd		
	Post-monsoon	Aureed Is	15	0.129	0.127	0.03-0.46
	Post-monsoon	Campbell Is	15	0.957	1.211	0.10-3.70
Al	Pre-monsoon	Campbell Is	13	10.62	9.88	2.3-31.0
	Pre-monsoon	Raine Is	21	1.58	0.40	0.95-2.6
	Post-monsoon	Aureed Is	15	4.64	6.57	1.4-28.0
	Post-monsoon	Campbell Is	15	8.52	8.27	2.8-37.0
As	Pre-monsoon	Campbell Is	13	683.1	182.5	350-950
	Pre-monsoon	Raine Is	21	447.6	230.4	230-1200
	Post-monsoon	Aureed Is	15	519.3	119.8	260-730.0
	Post-monsoon	Campbell Is	15	599.3	106.4	440-810
Cd	Pre-monsoon	Campbell Is	13	17.57	19.51	1.0-67.0
	Pre-monsoon	Raine Is	21	3.81	6.09	0.64-22.0
	Post-monsoon	Aureed Is	15	20.70	14.46	0.89-48.0
	Post-monsoon	Campbell Is	15	34.46	20.16	5.8-65.0
Co	Pre-monsoon	Campbell Is	13	43.39	8.38	26.0-57.0
	Pre-monsoon	Raine Is	21	42.38	11.47	27.0-69.0
	Post-monsoon	Aureed Is	15	92.47	18.54	70.0-140.0
	Post-monsoon	Campbell Is	15	74.93	20.91	39.0-110.0
Cr	Pre-monsoon	Campbell Is	13	1.72	0.15	1.5-2.0
	Pre-monsoon	Raine Is	21	2.78	0.97	1.7-6.4
	Post-monsoon	Aureed Is	15	2.60	0.65	1.9-4.2
	Post-monsoon	Campbell Is	15	2.87	0.48	2.1-4.2
Cu	Pre-monsoon	Campbell Is	13	2.15	0.93	1.2-4.0
	Pre-monsoon	Raine Is	21	1.54	0.39	0.87-2.2
	Post-monsoon	Aureed Is	15	1.45	0.50	0.86-2.6
	Post-monsoon	Campbell Is	15	4.28	3.28	1.4-13.0
Fe	Pre-monsoon	Campbell Is	13	463.8	103.2	360-760
	Pre-monsoon	Raine Is	21	351.9	78.5	220-490
	Post-monsoon	Aureed Is	15	514.7	71.2	380-680
	Post-monsoon	Campbell Is	15	587.3	137.6	400-900
Hg	Pre-monsoon	Campbell Is	13	0.88	0.38	0.12-1.3
	Pre-monsoon	Raine Is	21	1.09	0.19	0.74-1.5
	Post-monsoon	Aureed Is	15	0.72	0.11	0.61-0.91
	Post-monsoon	Campbell Is	15	0.84	0.21	0.47-1.1

(Appendix Table 58 continued over)

Metal	**Season**	**Sampling Station**	**n**	**Mean**	**S.D.**	**Range**
Mn	Pre-monsoon	Campbell Is	13	5376.9	1228.2	3400-6900
	Pre-monsoon	Raine Is	20	2895.0	866.6	1700-4600
	Post-monsoon	Aureed Is	15	8760.0	1639.2	6400-13000
	Post-monsoon	Campbell Is	15	6766.7	977.4	5000-9000
Ni	Pre-monsoon	Campbell Is	13	524.6	121.5	290-680
	Pre-monsoon	Raine Is	21	1694.8	728.4	740-3700
	Post-monsoon	Aureed Is	15	970.0	278.6	480-1400
	Post-monsoon	Campbell Is	15	787.3	254.3	410-1200
Pb	Pre-monsoon	Campbell Is	13	10.24	2.46	6.7-14.0
	Pre-monsoon	Raine Is	21	10.10	2.70	5.4-16.0
	Post-monsoon	Aureed Is	15	11.91	2.75	6.8-17.0
	Post-monsoon	Campbell Is	15	11.88	3.44	7.7-20.0
Se	Pre-monsoon	Campbell Is	13	30.8	4.7	24.0-37.0
	Pre-monsoon	Raine Is	21	34.1	6.5	24.0-48.0
	Post-monsoon	Aureed Is	15	25.7	8.9	16.0-48.0
	Post-monsoon	Campbell Is	15	22.2	4.6	16.0-31.0
Sr	Pre-monsoon	Campbell Is	13	nd		
	Pre-monsoon	Raine Is	21	nd		
	Post-monsoon	Aureed Is	15	966.0	170.8	720-1300
	Post-monsoon	Campbell Is	15	782.7	192.0	530-1100
U	Pre-monsoon	Campbell Is	13	nd		
	Pre-monsoon	Raine Is	21	nd		
	Post-monsoon	Aureed Is	15	2.20	0.73	1.0-3.5
	Post-monsoon	Campbell Is	15	3.83	0.51	3.1-4.8
Zn	Pre-monsoon	Campbell Is	13	23.87	25.99	3.1-89.0
	Pre-monsoon	Raine Is	21	3.83	1.70	1.5-7.3
	Post-monsoon	Campbell Is	15	38.00	34.33	2.9-96.0
	Post-monsoon	Aureed Is	15	12.89	15.38	2.0-57.0

Appendix Table 59. Analysis of Variance for differences in transformed (log_e(concentration+1)) metal concentration in the whole soft tissue of the oyster *P. margaritifera* from Aureed Island within two seasons.

Metal	Source of Variation	DF	MS	F-ratio	Significance
A1	Season	1	0.156	0.516	p=0.512
	Site{season}	4	0.302		
As	Season	1	0.093	5.231	p=0.084
	Site{season}	4	0.018		
Cd	Season	1	0.850	12.746	p=0.023
	Site{season}	4	0.067		
Co	Season	1	0.110	7.456	p=0.052
	Site{season}	4	0.015		
Cr	Season	1	1.147	17.993	p=0.013
	Site{season}	4	0.064		
Cu	Season	1	0.485	11.132	p=0.029
	Site{season}	4	0.044		
Fe	Season	1	0.401	2.622	p=0.181
	Site{season}	4	0.153		
Hg	Season	1	0.022	10.878	p=0.030
	Site{season}	4	0.002		
Mn	Season	1	3.220	72.486	p=0.001
	Site{season}	4	0.044		
Ni	Season	1	0.062	0.650	p=0.465
	Site({season}	4	0.096		
Pb	Season	1	0.064	18.960	p=0.012
	Site{season}	4	0.003		
Se	Season	1	0.078	7.800	p=0.059
	Site	4	0.010		
Zn	Season	1	2.454	16.773	p=0.015
	Site{season}	4	0.146		

Appendix Table 60. Analysis of Variance for differences in transformed (log_e(concentration+1)) metal concentration in the whole soft tissue of the oyster *P. margaritifera* from Aureed and Campbell Islands during the pre-monsoon season.

Metal	Source of variation	DF	MS	F-ratio	Significance
Al	Station	1	0.100	0.581	p=0.488
	Site{station}	4	0.173		
As	Station	1	0.004	0.027	p=0.877
	Site{station}	4	0.155		
Cd	Station	1	0.022	0.156	p=0.713
	Site{station}	4	0.142		
Co	Station	1	0.027	2.165	p=0.215
	Site{station}	4	0.013		
Cr	Station	1	0.603	9.846	p=0.035
	Site{station}	4	0.061		
Cu	Station	1	0.007	0.166	p=0.704
	Site{station}	4	0.040		
Fe	Station	1	0.613	3.920	p=0.119
	Site{station}	4	0.156		
Hg	Station	1	0.025	15.351	p=0.017
	Site{station}	4	0.002		
Mn	Station	1	0.487	2.193	p=0.213
	Site{station}	4	0.222		
Ni	Station	1	0.420	1.731	p=0.259
	Site{station}	4	0.242		
Pb	Station	1	0.003	0.249	p=0.644
	Site{station}	4	0.013		
Se	Station	1	1.431	34.072	p=0.004
	Site{station}	4	0.042		
Zn	Station	1	0.015	0.057	p=0.823
	Site{station}	4	0.259		

Appendix Table 61. Analysis of Variance for differences in transformed ($\log_e$ (concentration+1)) metal concentration in the whole soft tissue of the oyster *P. margaritifera* from Aureed Island and Kokope Reef during the post-monsoon season.

Metal	Source of variation	DF	MS	F-ratio	Significance
Al	Station	1	1.863	7.085	p=0.056
	Site{station}	4	0.263		
As	Station	1	0.158	1.242	p=0.328
	Site{station}	4	0.127		
Cd	Station	1	0.350	62.213	p=0.001
	Site{station}	4	0.006		
Co	Station	1	0.013	1.011	p=0.371
	Site{station}	4	0.013		
Cr	Station	1	0.651	46.375	p=0.002
	Site{station}	4	0.014		
Cu	Station	1	0.005	0.570	p=0.492
	Site{station}	4	0.009		
Fe	Station	1	1.500	13.659	p=0.021
	Site{station}	4	0.110		
Hg	Station	1	0.000	0.008	p=0.934
	Site{station}	4	0.000		
Mn	Station	1	0.383	7.162	p=0.055
	Site{station}	4	0.053		
Ni	Station	1	0.428	6.836	p=0.059
	Site{station}	4	0.063		
Pb	Station	1	0.024	28.190	p=0.006
	Site{station}	4	0.001		
Se	Station	1	0.002	0.083	p=0.788
	Site{station}	4	0.028		
Zn	Station	1	0.792	2.165	p=0.215
	Site{station}	4	0.366		

Appendix Table 62. Trace metal concentrations (mg kg^{-1} (dry weight)) in the whole soft tissue of the oyster *P. margaritifera* from three locations within two seasons. n = sample size. S.D. = standard deviation.

Metal	Season	Sampling Station	n	Mean	S.D.	Range
Al	Pre-monsoon	Aureed Is	15	163.1	74.7	81.0-320
	Pre-monsoon	Campbell Is	15	182.3	76.7	85.0-345
	Post-monsoon	Aureed Is	15	184.1	61.1	81.0-272
	Post-monsoon	Kokope Rf	15	307.5	122.2	107-636
As	Pre-monsoon	Aureed Is	15	83.0	29.5	44.0-140
	Pre-monsoon	Campbell Is	15	81.7	30.4	37.0-137
	Post-monsoon	Aureed Is	15	72.1	19.2	44.0-107
	Post-monsoon	Kokope Rf	15	64.2	24.5	37.0-120
Cd	Pre-monsoon	Aureed Is	15	10.59	3.39	5.9-19.6
	Pre-monsoon	Campbell Is	15	11.33	3.61	5.1-17.8
	Post-monsoon	Aureed Is	15	7.24	2.31	4.7-12.0
	Post-monsoon	Kokope Rf	15	9.27	2.93	4.4-15.0
Co	Pre-monsoon	Aureed Is	15	0.499	0.274	0.28-1.40
	Pre-monsoon	Campbell Is	15	0.415	0.284	0.20-1.30
	Post-monsoon	Aureed Is	15	0.318	0.133	0.15-0.62
	Post-monsoon	Kokope Rf	15	0.374	0.140	0.22-0.82
Cr	Pre-monsoon	Aureed Is	15	1.85	0.73	0.8-3.5
	Pre-monsoon	Campbell Is	15	1.14	0.52	0.5-1.9
	Post-monsoon	Aureed Is	15	3.13	0.60	2.3-4.5
	Post-monsoon	Kokope Rf	15	2.06	0.33	1.6-2.7
Cu	Pre-monsoon	Aureed Is	15	5.49	1.83	3.1-9.5
	Pre-monsoon	Campbell Is	15	5.16	1.10	3.5-6.9
	Post-monsoon	Aureed Is	15	3.88	0.57	2.8-4.7
	Post-monsoon	Kokope Rf	15	3.77	0.68	2.5-4.7
Fe	Pre-monsoon	Aureed Is	15	312.3	123.7	165-550
	Pre-monsoon	Campbell Is	15	233.3	83.1	85-370
	Post-monsoon	Aureed Is	15	237.3	57.3	141-312
	Post-monsoon	Kokope Rf	15	380.1	125.2	159-695
Hg	Pre-monsoon	Aureed Is	15	0.096	0.047	0.04-0.20
	Pre-monsoon	Campbell Is	15	0.034	0.012	0.02-0.06
	Post-monsoon	Aureed Is	15	0.038	0.014	0.02-0.06
	Post-monsoon	Kokope Rf	15	0.039	0.007	0.03-0.05
Mn	Pre-monsoon	Aureed Is	15	42.6	13.3	18.0-67.0
	Pre-monsoon	Campbell Is	15	34.2	14.9	13.0-59.0
	Post-monsoon	Aureed Is	15	22.0	8.3	10.0-38.0
	Post-monsoon	Kokope Rf	15	27.5	9.6	15.0-44.0

(Appendix Table 62 continued over)

Metal	Season	Sampling Station	n	Mean	S.D.	Range
Ni	Pre-monsoon	Aureed Is	15	3.23	0.97	1.7-4.9
	Pre-monsoon	Campbell Is	15	2.56	1.69	0.7-6.5
	Post-monsoon	Aureed Is	15	2.99	1.40	1.1-5.9
	Post-monsoon	Kokope Rf	15	2.03	0.62	1.3-3.3
Pb	Pre-monsoon	Aureed Is	15	0.205	0.065	0.15-0.35
	Pre-monsoon	Campbell Is	15	0.191	0.197	0.10-0.90
	Post-monsoon	Aureed Is	15	0.097	0.021	0.06-0.12
	Post-monsoon	Kokope Rf	15	0.162	0.050	0.07-0.28
Se	Pre-monsoon	Aureed Is	15	5.37	1.26	4.0-8.7
	Pre-monsoon	Campbell Is	15	3.23	1.02	0.2-4.4
	Post-monsoon	Aureed Is	15	4.67	0.48	4.0-6.0
	Post-monsoon	Kokope Rf	15	4.63	0.97	3.6-6.8
Zn	Pre-monsoon	Aureed Is	15	294.3	182.4	100-870
	Pre-monsoon	Campbell Is	15	329.8	231.4	82-965
	Post-monsoon	Aureed Is	15	157.8	72.4	73-325
	Post-monsoon	Kokope Rf	15	228.1	113.6	71-442

Appendix Table 63. Analysis of Variance for differences in transformed metal concentration ($\log_e$(concentration+1)) in the whole soft tissue of the oyster *H. hyotis* from Aureed Island and Kokope Reef within two seasons.

Metal	Source of variation	DF	MS	F-ratio	Significance
Al	Season	1	2.318	2.956	p=0.124
	Station	1	0.510	0.651	p=0.443
	Season*Station	1	0.002	0.003	p=0.956
	Site{season*station}	8	0.784		
As	Season	1	0.272	1.719	p=0.226
	Station	1	1.090	6.898	p=0.030
	Season*Station	1	0.001	0.004	p=0.951
	Site{season*station}	8	0.158		
Cd	Season	1	0.267	0.698	p=0.428
	Station	1	0.254	0.664	p=0.439
	Season*Station	1	0.095	0.249	p=0.632
	Site{season*station}	8	0.382		
Co	Season	1	0.001	0.071	p=0.797
	Station	1	0.000	0.028	p=0.870
	Season*Station	1	0.000	0.000	p=0.992
	Site{season*station}	8	0.010		
Cr	Season	1	1.400	20.594	p=0.002
	Station	1	0.703	10.337	p=0.012
	Season*Station	1	0.209	3.068	p=0.118
	Site{season*station}	8	0.068		
Cu	Season	1	2.759	6.063	p=0.039
	Station	1	0.038	0.083	p=0.781
	Season*Station	1	0.662	1.455	p=0.262
	Site{season*station}	8	0.455		
Fe	Season	1	1.078	1.253	p=0.295
	Station	1	1.431	1.664	p=0.233
	Season*Station	1	0.967	1.124	p=0.320
	Site{season*station}	8	0.860		
Hg	Season	1	0.002	2.205	p=0.176
	Station	1	0.000	0.084	p=0.780
	Season*Station	1	0.000	0.087	p=0.775
	Site{season*station}	8	0.001		
Mn	Season	1	0.820	19.989	p=0.002
	Station	1	0.366	8.932	p=0.017
	Season*Station	1	0.881	21.481	p=0.002
	Site{season*station}	8	0.041		
Ni	Season	1	0.003	0.010	p=0.921
	Station	1	0.000	0.000	p=0.996
	Season*Station	1	0.107	0.335	p=0.578
	Site{season*station}	8	0.318		

(Appendix Table 63 continued over)

Metal	Source of variation	DF	MS	F-ratio	Significance
Pb	Season	1	0.231	2.163	p=0.180
	Station	1	0.174	1.626	p=0.238
	Season*Station	1	0.085	0.797	p=0.398
	Site{season*station}	8	0.107		
Se	Season	1	0.252	6.997	p=0.029
	Station	1	0.119	3.309	p=0.106
	Season*Station	1	0.037	1.027	p=0.340
	Site{season*station}	8	0.036		
Zn	Season	1	5.217	2.593	p=0.146
	Station	1	2.676	1.330	p=0.282
	Season*Station	1	0.143	0.071	p=0.797
	Site{season*station}	8	2.012		

Appendix Table 64. Trace metal concentrations (mg kg^{-1} (dry weight)) in the whole soft tissue of the oyster *H. hyotis* from two locations within two seasons. n = sample size. S.D. = standard deviation.

Metal	Season	Sampling Station	n	Mean	S.D.	Range
Al	Pre-monsoon	Aureed Is	15	144.3	59.4	70-245
	Pre-monsoon	Kokope Rf	15	192.7	163.1	85-730
	Post-monsoon	Aureed Is	15	97.0	36.4	22-152
	Post-monsoon	Kokope Rf	15	113.5	37.3	63-189
As	Pre-monsoon	Aureed Is	15	50.4	11.4	34-72
	Pre-monsoon	Kokope Rf	15	67.3	24.4	45-140
	Post-monsoon	Aureed Is	15	57.1	11.5	38-79
	Post-monsoon	Kokope Rf	15	76.6	19.8	45-114
Cd	Pre-monsoon	Aureed Is	15	2.04	0.99	0.50-3.6
	Pre-monsoon	Kokope Rf	15	1.38	0.45	0.78-2.6
	Post-monsoon	Aureed Is	15	2.12	0.71	1.30-3.7
	Post-monsoon	Kokope Rf	15	1.97	0.70	0.91-3.3
Co	Pre-monsoon	Aureed Is	15	0.200	0.076	0.10-0.30
	Pre-monsoon	Kokope Rf	15	0.205	0.074	0.11-0.41
	Post-monsoon	Aureed Is	15	0.191	0.045	0.14-0.31
	Post-monsoon	Kokope Rf	15	0.195	0.039	0.14-0.29
Cr	Pre-monsoon	Aureed Is	15	1.46	0.41	1.0-2.5
	Pre-monsoon	Kokope Rf	15	1.23	0.40	0.6-2.3
	Post-monsoon	Aureed Is	15	2.73	0.33	2.2-3.4
	Post-monsoon	Kokope Rf	15	1.67	0.23	1.3-2.2
Cu	Pre-monsoon	Aureed Is	15	8.41	3.04	2.7-13.0
	Pre-monsoon	Kokope Rf	15	10.30	4.46	3.0-19.0
	Post-monsoon	Aureed Is	15	6.55	2.95	2.8-16.0
	Post-monsoon	Kokope Rf	15	4.68	1.48	2.7-7.6
Fe	Pre-monsoon	Aureed Is	15	153.7	53.9	15-260
	Pre-monsoon	Kokope Rf	15	283.3	193.3	125-840
	Post-monsoon	Aureed Is	15	137.6	28.5	91-186
	Post-monsoon	Kokope Rf	15	147.0	40.9	105-252
Hg	Pre-monsoon	Aureed Is	15	0.035	0.011	0.02-0.06
	Pre-monsoon	Kokope Rf	15	0.041	0.031	0.01-0.10
	Post-monsoon	Aureed Is	15	0.025	0.011	0.02-0.06
	Post-monsoon	Kokope Rf	15	0.025	0.016	0.02-0.08
Mn	Pre-monsoon	Aureed Is	15	3.92	0.94	2.3-5.3
	Pre-monsoon	Kokope Rf	15	6.66	3.08	2.4-16.0
	Post-monsoon	Aureed Is	15	3.91	0.57	2.9-4.9
	Post-monsoon	Kokope Rf	15	3.52	0.69	2.5-4.8

(Appendix Table 64 continued over)

Metal	Season	Sampling Station	n	Mean	SD	Range
Ni	Pre-monsoon	Aureed Is	15	0.723	0.443	0.30-1.8
	Pre-monsoon	Kokope Rf	15	0.931	0.903	0.50-4.1
	Post-monsoon	Aureed Is	15	0.808	0.233	0.57-1.5
	Post-monsoon	Kokope Rf	15	0.662	0.226	0.41-1.3
Pb	Pre-monsoon	Aureed Is	15	<0.30	bdl	bdl
	Pre-monsoon	Kokope Rf	15	0.492	0.864	0.12-3.6
	Post-monsoon	Aureed Is	15	0.095	0.016	0.07-0.12
	Post-monsoon	Kokope Rf	15	0.132	0.046	0.07-0.24
Se	Pre-monsoon	Aureed Is	15	2.32	0.61	1.6-3.4
	Pre-monsoon	Kokope Rf	15	2.84	0.82	1.6-4.5
	Post-monsoon	Aureed Is	15	2.93	0.34	2.5-3.5
	Post-monsoon	Kokope Rf	15	3.09	0.38	2.5-3.8
Zn	Pre-monsoon	Aureed Is	15	539.3	229.4	210-945
	Pre-monsoon	Kokope Rf	15	799.4	484.9	327-1800
	Post-monsoon	Aureed Is	15	325.5	332.9	79-1420
	Post-monsoon	Kokope Rf	15	481.5	287.5	193-1070

Appendix Table 65. Analysis of Variance for differences in transformed ($\log_e$(concentration+1)) metal concentration in the whole soft tissue of the oyster *C. plinthota* from Aureed Island within two seasons.

Metal	Source of variation	DF	MS	F-ratio	Significance
Al	Season	1	1.893	4.772	p=0.094
	Site{season}	4	0.397		
As	Season	1	0.202	0.851	p=0.408
	Site{season}	4	0.238		
Cd	Season	1	0.157	0.577	p=0.490
	Site{season}	4	0.272		
Co	Season	1	0.261	0.457	p=0.536
	Site{season}	4	0.571		
Cr	Season	1	0.064	0.353	p=0.584
	Site{season}	4	0.181		
Cu	Season	1	0.682	3.607	p=0.130
	Site{season}	4	0.189		
Fe	Season	1	1.224	3.414	p=0.138
	Site{season}	4	0.358		
Hg	Season	1	0.095	247.692	p<0.001
	Site{season}	4	0.000		
Mn	Season	1	0.137	8.618	p=0.043
	Site{season}	4	0.016		
Ni	Season	1	0.156	0.308	p=0.609
	Site{season}	4	0.506		
Pb	Season	1	0.000	0.000	p=0.991
	Site{season}	4	0.078		
Se	Season	1	0.068	0.168	p=0.703
	Site{season}	4	0.403		
Zn	Season	1	0.010	0.027	p=0.877
	Site{season}	4	0.370		

Appendix Table 66. Analysis of Variance for differences in transformed ($\log_e$(concentration+1)) metal concentration in the whole soft tissue of the oyster *C. plinthota* from Aureed Island and Kokope Reef during the post-monsoon season.

Metal	Source of variation	DF	MS	F-ratio	Significance
Al	Station	1	1.135	1.933	p=0.237
	Site{station}	4	0.587		
As	Station	1	0.059	0.477	p=0.528
	Site{station}	4	0.125		
Cd	Station	1	0.200	0.392	p=0.565
	Site{station}	4	0.510		
Co	Station	1	0.087	0.098	p=0.770
	Site{station}	4	0.893		
Cr	Station	1	2.183	16.183	p=0.016
	Site{station}	4	0.135		
Cu	Station	1	0.117	0.084	p=0.787
	Site{station}	4	1.404		
Fe	Station	1	2.362	5.439	p=0.080
	Site{station}	4	0.434		
Hg	Station	1	0.006	7.113	p=0.056
	Site{station}	4	0.001		
Mn	Station	1	1.111	7.033	p=0.057
	Site{station}	4	0.158		
Ni	Station	1	0.216	0.410	p=0.557
	Site{station}	4	0.527		
Pb	Station	1	0.127	3.277	p=0.145
	Site{station}	4	0.039		
Se	Station	1	0.090	0.426	p=0.550
	Site{station}	4	0.212		
Zn	Station	1	0.004	0.052	p=0.830
	Site{station}	4	0.084		

Appendix Table 67. Trace metal concentrations (mg kg^{-1} (dry weight)) in the whole soft tissue of the oyster *C. plinthota* from two locations within two seasons. n = sample size. S.D. = standard deviation. bdl = below detection limit.

Metal	Season	Sampling Station	n	Mean	S.D.	Range
Al	Pre-monsoon	Aureed Is	24	51.9	29.6	16.0-130.0
	Post-monsoon	Aureed Is	15	79.5	37.6	28.9-167.4
	Post-monsoon	Kokope Rf	15	116.7	53.5	45.9-244.9
As	Pre-monsoon	Aureed Is	24	193.0	301.9	59.0-1400
	Post-monsoon	Aureed Is	15	110.2	39.1	59.0-208
	Post-monsoon	Kokope Rf	15	155.8	276.7	46.0-1150
Cd	Pre-monsoon	Aureed Is	24	31.60	28.69	4.2-130
	Post-monsoon	Aureed Is	15	23.67	14.44	3.3-50.0
	Post-monsoon	Kokope Rf	15	21.03	19.28	4.7-78.0
Co	Pre-monsoon	Aureed Is	24	8.26	17.49	1.5-69.0
	Post-monsoon	Aureed Is	15	5.69	4.73	1.7-21.0
	Post-monsoon	Kokope Rf	15	7.31	7.53	1.5-31.0
Cr	Pre-monsoon	Aureed Is	24	4.68	2.83	1.9-12.0
	Post-monsoon	Aureed Is	15	5.25	3.49	2.4-11.7
	Post-monsoon	Kokope Rf	15	9.19	4.25	4.0-20.0
Cu	Pre-monsoon	Aureed Is	24	15.78	24.11	3.3-110
	Post-monsoon	Aureed Is	15	15.45	10.89	4.1-37.5
	Post-monsoon	Kokope Rf	15	28.20	36.47	2.1-109
Fe	Pre-monsoon	Aureed Is	24	336.7	169.4	130-770
	Post-monsoon	Aureed Is	15	241.9	218.4	116-1016
	Post-monsoon	Kokope Rf	15	433.0	346.3	202-1495
Hg	Pre-monsoon	Aureed Is	24	0.151	0.058	0.10-0.34
	Post-monsoon	Aureed Is	15	0.039	0.032	0.01-0.13
	Post-monsoon	Kokope Rf	15	0.069	0.047	0.03-0.21
Mn	Pre-monsoon	Aureed Is	24	3.41	2.03	1.2-8.6
	Post-monsoon	Aureed Is	15	2.61	0.63	1.6-4.1
	Post-monsoon	Kokope Rf	15	4.53	1.87	1.7-7.9
Ni	Pre-monsoon	Aureed Is	24	24.4	45.4	6.1-190
	Post-monsoon	Aureed Is	15	12.3	5.64	6.0-27.0
	Post-monsoon	Kokope Rf	15	18.3	18.9	5.9-80.0
Pb	Pre-monsoon	Aureed Is	24	0.548	1.067	0.13-4.6
	Post-monsoon	Aureed Is	15	0.393	0.297	0.02-1.1
	Post-monsoon	Kokope Rf	15	bdl		bdl
Se	Pre-monsoon	Aureed Is	24	9.11	18.09	1.6-72.0
	Post-monsoon	Aureed Is	15	4.20	1.18	2.7-6.4
	Post-monsoon	Kokope Rf	15	5.21	3.69	2.8-18.1
Zn	Pre-monsoon	Aureed Is	24	91.46	45.80	24.0-220
	Post-monsoon	Aureed Is	15	87.28	39.11	45.8-162
	Post-monsoon	Kokope Rf	15	85.23	24.07	52.9-132

Appendix Table 68. Analysis of Variance for differences in transformed (log_e(concentration+1)) metal concentration in the muscle tissue of the gastropod *T. niloticus* from Aureed Island within two seasons.

Metal	Source of variation	DF	MS	F-ratio	Significance
Al	Season	1	0.002	0.038	p=0.855
	Site{season}	4	0.041		
As	Season	1	0.063	1.664	p=0.267
	Site{season}	4	0.038		
Cd	Season	1	0.043	4.140	p=0.112
	Site{season}	4	0.010		
Co	Season	1	0.003	6.858	p=0.059
	Site{season}	4	0.000		
Cr	Season	1	0.622	19.482	p=0.012
	Site{season}	4	0.032		
Cu	Season	1	0.042	0.692	p=0.452
	Site{season}	4	0.060		
Fe	Season	1	0.430	9.913	p=0.035
	Site{season}	4	0.043		
Hg	Season	1	0.002	4.214	p=0.109
	Site{season}	4	0.000		
Mn	Season	1	0.037	1.340	p=0.311
	Site{season}	4	0.028		
Ni	Season	1	0.005	1.291	p=0.319
	Site{season}	4	0.004		
Pb	Season	1	0.338	10.318	p=0.033
	Site{season}	4	0.033		
Se	Season	1	0.089	7.067	p=0.056
	Site{season}	4	0.013		
Zn	Season	1	0.590	3.812	p=0.123
	Site{season}	4	0.155		

Appendix Table 69. Analysis of Variance for differences in transformed (log_e(concentration+1)) metal concentration in the muscle tissue of the gastropod *T. niloticus* from Aureed Island, Dungeness Reef, Kokope Reef and Raine Island during the pre-monsoon season. Raine Island data provided by Barry and Rayment (1992).

Metal	Source of variation	DF	MS	F-ratio	Significance
Al	Station	3	0.923	3.529	p=0.088
	Site{station}	6	0.262		
As	Station	3	0.480	2.577	p=0.149
	Site{station}	6	0.186		
Cd	Station	3	0.023	2.736	p=0.136
	Site{station}	6	0.009		
Co	Station	3	0.005	6.428	p=0.026
	Site{station}	6	0.001		
Cr	Station	3	0.007	0.452	p=0.725
	Site{station}	6	0.016		
Cu	Station	3	0.322	4.116	p=0.066
	Site{station}	6	0.078		
Fe	Station	3	0.226	1.430	p=0.324
	Site{station}	6	0.158		
Hg	Station	3	0.000	0.395	p=0.761
	Site{station}	6	0.001		
Mn	Station	3	2.682	55.630	p<0.001
	Site{station}	6	0.048		
Ni	Station	3	0.126	21.058	p=0.001
	Site{station}	6	0.006		
Pb	Station	3	0.029	0.849	p=0.516
	Site{station}	6	0.035		
Se	Station	3	0.027	3.742	p=0.079
	Site{station}	6	0.007		
Zn	Station	3	6.234	21.904	p=0.001
	Site{station}	6	0.285		

Appendix Table 70. Analysis of Variance for differences in transformed (log_e(concentration+1)) metal concentration in the muscle tissue of the gastropod *T. niloticus* from Aureed Island and Kokope Reef during the post-monsoon season.

Metal	Source of variation	DF	MS	F-ratio	Significance
Al	Station	1	0.760	14.193	p=0.020
	Site{station}	4	0.054		
As	Station	1	0.025	0.598	p=0.482
	Site{station}	4	0.041		
Cd	Station	1	0.047	8.038	p=0.047
	Site{station}	4	0.006		
Co	Station	1	0.015	30.130	p=0.005
	Site{station}	4	0.000		
Cr	Station	1	0.000	0.013	p=0.913
	Site{station}	4	0.028		
Cu	Station	1	0.037	0.827	p=0.415
	Site{station}	4	0.044		
Fe	Station	1	0.158	2.268	p=0.207
	Site{station}	4	0.070		
Hg	Station	1	0.000	13.141	p=0.022
	Site{station}	4	0.000		
Mn	Station	1	4.487	15.587	p=0.017
	Site{station}	4	0.288		
Ni	Station	1	0.055	6.227	p=0.067
	Site{station}	4	0.009		
Pb	Station	1	0.001	24.154	p=0.008
	Site{station}	4	0.000		
Se	Station	1	0.010	0.397	p=0.563
	Site{station}	4	0.024		
Zn	Station	1	2.485	32.198	p=0.005
	Site{station}	4	0.077		

Appendix Table 71. Aluminium (Al) concentrations in the muscle tissue of the gastropod *T. niloticus* from four locations within two seasons. Metal concentrations are in mg kg^{-1} (dry weight). n = sample size. S.D. = standard deviation. Raine Island data provided by Barry and Rayment (1992).

Season	**Sampling Station**	**n**	**Mean**	**S.D.**	**Range**
Pre-monsoon	Aureed Is	15	1.07	0.51	0.46-2.2
Pre-monsoon	Dungeness Rf	15	3.13	3.23	1.2-14.0
Pre-monsoon	Kokope Rf	2	3.35	1.63	2.2-4.5
Pre-monsoon	Raine Is	20	1.85	1.84	0.75-9.4
Post-monsoon	Aureed Is	15	1.07	0.66	0.36-2.8
Post-monsoon	Kokope Rf	15	1.88	1.03	0.70-4.5

Appendix Table 72. Arsenic (As) concentrations in the muscle tissue of the gastropod *T. niloticus* from four locations within two seasons. Metal concentrations are in mg kg^{-1} (dry weight). n = sample size. S.D. = standard deviation. Raine Island data provided by Barry and Rayment (1992).

Season	**Sampling Station**	**n**	**Mean**	**S.D.**	**Range**
Pre-monsoon	Aureed Is	15	24.67	3.83	18.0-30.0
Pre-monsoon	Dungeness Rf	15	31.73	7.96	21.0-52.0
Pre-monsoon	Kokope Rf	2	23.00	1.41	22.0-24.0
Pre-monsoon	Raine Is	20	20.85	6.99	11.0-34.0
Post-monsoon	Aureed Is	15	27.07	3.83	21.0-34.0
Post-monsoon	Kokope Rf	15	25.73	5.01	16.0-34.0

Appendix Table 73. Cadmium (Cd) concentrations in the muscle tissue of the gastropod *T. niloticus* from four locations within two seasons. Metal concentrations are in mg kg^{-1} (dry weight). n = sample size. S.D. = standard deviation. Raine Island data provided by Barry and Rayment (1992).

Season	**Sampling Station**	**n**	**Mean**	**S.D.**	**Range**
Pre-monsoon	Aureed Is	15	0.329	0.160	0.18-0.83
Pre-monsoon	Dungeness Rf	15	0.380	0.105	0.25-0.66
Pre-monsoon	Kokope Rf	2	0.265	0.035	0.24-0.29
Pre-monsoon	Raine Is	20	0.443	0.172	0.18-0.80
Post-monsoon	Aureed Is	15	0.225	0.055	0.18-0.34
Post-monsoon	Kokope Rf	15	0.329	0.111	0.17-0.57

Appendix Table 74. Cobalt (Co) concentrations in the muscle tissue of the gastropod *T. niloticus* from four locations within two seasons. Metal concentrations are in mg kg^{-1} (dry weight). Means with the same superscript indicate a significant difference among locations ($p<=0.05$ by Tukey's Test). n = sample size. S.D. = standard deviation. Raine Island data provided by Barry and Rayment (1992).

Season	Sampling Station	n	Mean	SD	Range
Pre-monsoon	Aureed Is	15	0.042^{a}	0.009	0.02-0.06
Pre-monsoon	Dungeness Rf	15	0.062	0.012	0.05-0.09
Pre-monsoon	Kokope Rf	2	0.120^{ab}	0.000	0.12-0.12
Pre-monsoon	Raine Is	20	0.037^{b}	0.018	0.02-0.07
Post-monsoon	Aureed Is	15	0.021	0.014	0.01-0.04
Post-monsoon	Kokope Rf	15	0.067	0.018	0.05-0.10

Appendix Table 75. Chromium (Cr) concentrations in the muscle tissue of the gastropod *T. niloticus* from four locations within two seasons. Metal concentrations are in mg kg^{-1} (dry weight). n = sample size. S.D. = standard deviation. Raine Island data provided by Barry and Rayment (1992).

Season	Sampling Station	n	Mean	S.D.	Range
Pre-monsoon	Aureed Is	15	0.681	0.175	0.38-1.20
Pre-monsoon	Dungeness Rf	15	0.710	0.094	0.61-0.95
Pre-monsoon	Kokope Rf	2	0.530	0.014	0.52-0.54
Pre-monsoon	Raine Is	20	0.687	0.148	0.48-1.10
Post-monsoon	Aureed Is	15	1.247	0.276	0.76-1.70
Post-monsoon	Kokope Rf	15	1.220	0.142	0.90-1.40

Appendix Table 76. Copper (Cu) concentrations in the muscle tissue of the gastropod *T. niloticus* from four locations within two seasons. Metal concentrations are in mg kg^{-1} (dry weight). n = sample size. S.D. = standard deviation. Raine Island data provided by Barry and Rayment (1992).

Season	Sampling Station	n	Mean	S.D.	Range
Pre-monsoon	Aureed Is	15	10.92	3.01	7.1-18.0
Pre-monsoon	Dungeness Rf	15	15.20	3.32	9.0-22.0
Pre-monsoon	Kokope Rf	2	15.00	1.41	14.0-16.0
Pre-monsoon	Raine Is	20	11.84	3.87	7.2-21.0
Post-monsoon	Aureed Is	15	12.10	3.92	5.2-19.0
Post-monsoon	Kokope Rf	15	11.13	3.55	6.2-17.0

Appendix Table 77. Iron (Fe) concentrations in the muscle tissue of the gastropod *T. niloticus* from four locations within two seasons. Metal concentrations are in mg kg^{-1} (dry weight). n = sample size. S.D. = standard deviation. Raine Island data provided by Barry and Rayment (1992).

Season	Sampling Station	n	Mean	S.D.	Range
Pre-monsoon	Aureed Is	15	27.13	7.35	17.0-45.0
Pre-monsoon	Dungeness Rf	15	34.40	7.13	28.0-52.0
Pre-monsoon	Kokope Rf	2	27.00	8.49	21.0-33.0
Pre-monsoon	Raine Is	20	27.00	11.29	10.0-59.0
Post-monsoon	Aureed Is	15	20.80	3.69	16.0-28.0
Post-monsoon	Kokope Rf	15	24.93	7.60	13.0-38.0

Appendix Table 78. Mercury (Hg) concentrations in the muscle tissue of the gastropod *T. niloticus* from four locations within two seasons. Metal concentrations are in mg kg^{-1} (dry weight). n = sample size. S.D. = standard deviation. Raine Island data provided by Barry and Rayment (1992).

Season	Sampling Station	n	Mean	S.D.	Range
Pre-monsoon	Aureed Is	15	0.026	0.020	0.01-0.08
Pre-monsoon	Dungeness Rf	15	0.029	0.016	0.02-0.08
Pre-monsoon	Kokope Rf	2	0.030	0.014	0.02-0.04
Pre-monsoon	Raine Is	20	0.019	0.014	0.01-0.06
Post-monsoon	Aureed Is	15	0.011	0.004	0.01-0.02
Post-monsoon	Kokope Rf	15	0.019	0.006	0.01-0.03

Appendix Table 79. Manganese (Mn) concentrations in the muscle tissue of the gastropod *T. niloticus* from four locations within two seasons. Metal concentrations are in mg kg^{-1} (dry weight). Means with the same superscript indicate a significant difference among locations (p<=0.05 by Tukey's Test). n = sample size. S.D. = standard deviation. Raine Island data provided by Barry and Rayment (1992).

Season	Sampling Station	n	Mean	S.D.	Range
Pre-monsoon	Aureed Is	15	0.622^{a}	0.107	0.41-0.84
Pre-monsoon	Dungeness Rf	15	0.825^{b}	0.249	0.20-1.10
Pre-monsoon	Kokope Rf	2	11.50^{abc}	2.121	10.0-13.0
Pre-monsoon	Raine Is	20	0.560^{c}	0.140	0.41-0.92
Post-monsoon	Aureed Is	15	0.756	0.271	0.38-1.30
Post-monsoon	Kokope Rf	15	3.364	2.679	0.50-10.0

Appendix Table 80. Nickel (Ni) concentrations in the muscle tissue of the gastropod *T. niloticus* from four locations within two seasons. Metal concentrations are in mg kg^{-1} (dry weight). Means with the same superscript indicate a significant difference among locations (p<=0.05 by Tukey's Test). n = sample size. S.D. = standard deviation.. Raine Island data provided by Barry and Rayment (1992).

Season	Sampling Station	n	Mean	S.D.	Range
Pre-monsoon	Aureed Is	15	0.095^{ab}	0.040	0.02-0.18
Pre-monsoon	Dungeness Rf	15	0.128^{cd}	0.063	0.03-0.29
Pre-monsoon	Kokope Rf	2	0.630^{ace}	0.099	0.56-0.70
Pre-monsoon	Raine Is	20	0.244^{bde}	0.068	0.14-0.42
Post-monsoon	Aureed Is	15	0.123	0.046	0.04-0.19
Post-monsoon	Kokope Rf	15	0.227	0.102	0.11-0.48

Appendix Table 81. Lead (Pb) concentrations in the muscle tissue of the gastropod *T. niloticus* from four locations within two seasons. Metal concentrations are in mg kg^{1} (dry weight). n = sample size. S.D. = standard deviation. Raine Island data provided by Barry and Rayment (1992).

Season	Sampling Station	n	Mean	S.D.	Range
Pre-monsoon	Aureed Is	15	0.315	0.579	0.07-2.40
Pre-monsoon	Dungeness Rf	15	0.129	0.052	0.05-0.26
Pre-monsoon	Kokope Rf	2	0.120	0.000	0.12-0.12
Pre-monsoon	Raine Is	20	0.185	0.241	0.08-1.20
Post-monsoon	Aureed Is	15	0.012	0.006	0.01-0.03
Post-monsoon	Kokope Rf	15	0.021	0.011	0.01-0.04

Appendix Table 82. Selenium (Se) concentrations in the muscle tissue of the gastropod *T. niloticus* from four locations within two seasons. Metal concentrations are in mg kg^{-1} (dry weight). n = sample size. S.D. = standard deviation. Raine Island data provided by Barry and Rayment (1992).

Season	Sampling Station	n	Mean	S.D.	Range
Pre-monsoon	Aureed Is	15	0.716	0.128	0.43-0.88
Pre-monsoon	Dungeness Rf	15	0.725	0.134	0.47-0.92
Pre-monsoon	Kokope Rf	2	0.845	0.021	0.83-0.86
Pre-monsoon	Raine Is	20	0.595	0.094	0.46-0.85
Post-monsoon	Aureed Is	15	0.917	0.175	0.55-1.20
Post-monsoon	Kokope Rf	15	0.999	0.259	0.12-1.20

Appendix Table 83. Zinc (Zn) concentrations in the muscle tissue of the gastropod *T. niloticus* from four locations within two seasons. Metal concentrations are in mg kg^{-1} (dry weight). Means with the same superscript indicate a significant difference among locations (p<=0.05 by Tukey's Test). n = sample size. S.D. = standard deviation. Raine Island data provided by Barry and Rayment (1992).

Season	Sampling Station	n	Mean	S.D.	Range
Pre-monsoon	Aureed Is	15	18.47^{ab}	7.08	10.0-37.0
Pre-monsoon	Dungeness Rf	15	41.60^{ac}	15.39	16.0-63.0
Pre-monsoon	Kokope Rf	2	39.50^{d}	4.95	36.0-43.0
Pre-monsoon	Raine Is	20	8.75^{bcd}	3.38	4.9-17.0
Post-monsoon	Aureed Is	15	25.31	9.27	6.6-41.0
Post-monsoon	Kokope Rf	15	42.73	5.47	35.0-54.0

Appendix Table 84. Analysis of Variance for differences in transformed metal concentration ($\log_e$(concentration+1)) in the muscle tissue of the gastropod *S. luhuanus* from Aureed and Campbell Islands within two seasons.

Metal	Source of variation	DF	MS	F-ratio	Significance
Al	Season	1	0.530	0.104	p=0.755
	Station	1	0.078	0.015	p=0.904
	Season*Station	1	11.478	2.252	p=0.172
	Site{season*station}	8	5.097		
As	Season	1	0.084	0.248	p=0.632
	Station	1	0.433	1.285	p=0.290
	Season*Station	1	0.014	0.042	p=0.843
	Site{season*station}	8	0.337		
Cd	Season	1	0.035	0.031	p=0.865
	Station	1	1.580	1.372	p=0.275
	Season*Station	1	0.180	0.157	p=0.703
	Site{season*station}	8	1.152		
Co	Season	1	0.115	2.450	p=0.156
	Station	1	0.010	0.209	p=0.659
	Season*Station	1	0.032	0.680	p=0.434
	Site{season*station}	8	0.047		
Cr	Season	1	1.179	7.192	p=0.028
	Station	1	0.057	0.347	p=0.572
	Season*Station	1	0.007	0.044	p=0.838
	Site{season*station}	8	0.164		
Cu	Season	1	2.965	1.365	p=0.276
	Station	1	2.863	1.318	p=0.284
	Season*Station	1	0.415	0.191	p=0.674
	Site{season*station}	8	2.172		
Fe	Season	1	4.140	11.896	p=0.009
	Station	1	0.234	0.672	p=0.436
	Season*Station	1	0.915	2.629	p=0.144
	Site{season*station}	8	0.348		
Hg	Season	1	0.002	0.850	p=0.383
	Station	1	0.011	5.317	p=0.050
	Season*Station	1	0.005	2.471	p=0.155
	Site{season*station}	8	0.002		
Mn	Season	1	3.190	1.775	p=0.219
	Station	1	2.689	1.497	p=0.256
	Season*Station	1	0.000	0.000	p=0.999
	Site{season*station}	8	1.797		

(Appendix Table 84 continued over)

Metal	Source of variation	DF	MS	F-ratio	Significance
Ni	Season	1	1.613	1.276	p=0.291
	Station	1	1.350	1.068	p=0.332
	Season*Station	1	0.737	0.583	p=0.467
	Site{season*station}	8	1.264		
Pb	Season	1	0.305	4.012	p=0.080
	Station	1	0.087	1.145	p=0.316
	Season*Station	1	0.082	1.076	p=0.330
	Site{season*station}	8	0.076		
Se	Season	1	0.550	1.207	p=0.304
	Station	1	0.023	0.051	p=0.827
	Season*Station	1	0.091	0.200	p=0.667
	Site{season*station}	8	0.456		
Zn	Season	1	2.472	2.533	p=0.150
	Station	1	2.629	2.694	p=0.139
	Season*Station	1	0.834	0.854	p=0.382
	Site{season*station}	8	0.976		

Appendix Table 85. Analysis of Variance for differences in transformed (log_e(concentration+1)) metal concentration in the muscle tissue of the gastropod *S. luhuanus* from two habitats at Aureed Island during the pre-monsoon season.

Metal	**Source of variation**	**DF**	**MS**	**F-ratio**	**Significance**
Al	Habitat	1	12.497	2.675	p=0.177
	Site{habitat}	4	4.672		
As	Habitat	1	0.425	3.062	p=0.155
	Site{habitat}	4	0.139		
Cd	Habitat	1	1.141	11.866	p=0.026
	Site{habitat}	4	0.096		
Co	Habitat	1	0.012	0.667	p=0.460
	Site{habitat}	4	0.019		
Cr	Habitat	1	0.087	1.048	p=0.364
	Site{habitat}	4	0.083		
Cu	Habitat	1	0.022	0.037	p=0.857
	Site{habitat}	4	0.593		
Fe	Habitat	1	3.766	2.624	p=0.181
	Site{habitat}	4	1.435		
Hg	Habitat	1	0.000	0.044	p=0.844
	Site{habitat}	4	0.001		
Mn	Habitat	1	1.042	1.231	p=0.329
	Site{habitat}	4	0.846		
Ni	Habitat	1	0.711	0.724	p=0.443
	Site{habitat}	4	0.982		
Pb	Habitat	1	0.015	1.106	p=0.352
	Site{habitat}	4	0.014		
Se	Habitat	1	0.180	3.955	p=0.118
	Site{habitat}	4	0.045		
Zn	Habitat	1	0.097	0.136	p=0.731
	Site{habitat}	4	0.715		

Appendix Table 86. Trace metal concentrations within liver and muscle tissue of the gastropod *S. luhanus* from two habitats and two locations within two seasons. Metal concentrations are in mg kg^{-1} (dry weight). n = sample size. S.D. = standard deviation.

Metal	Season Station	Sampling	Habitat	n	Mean	S.D.	Range
Al	Pre-monsoon	Aureed Is	Fore-reef	15	4.5	2.5	1.0-9.0
	Pre-monsoon	Campbell Is	Fore-reef	15	17.6	15.8	1.7-51.0
	Pre-monsoon	Campbell Is	Back-reef	15	80.7	110.4	11.0-385
	Post-monsoon	Aureed Is	Fore-reef	15	16.6	6.8	8.0-30.9
	Post-monsoon	Campbell Is	Fore-reef	7	5.9	4.7	1.3-14.3
As	Pre-monsoon	Aureed Is	Fore-reef	15	24.5	3.9	19.0-31.0
	Pre-monsoon	Campbell Is	Fore-reef	15	20.9	3.9	14.0-27.0
	Pre-monsoon	Campbell Is	Back-reef	15	16.9	5.6	7.2-27.0
	Post-monsoon	Aureed Is	Fore-reef	15	28.4	8.5	20.0-53.0
	Post-monsoon	Campbell Is	Fore-reef	7	22.4	4.5	13.0-26.0
Cd	Pre-monsoon	Aureed Is	Fore-reef	15	3.71	1.87	1.5-7.6
	Pre-monsoon	Campbell Is	Fore-reef	15	6.28	0.96	4.7-8.2
	Pre-monsoon	Campbell Is	Back-reef	15	4.07	1.35	2.3-6.0
	Post-monsoon	Aureed Is	Fore-reef	15	4.16	2.41	1.5-9.2
	Post-monsoon	Campbell Is	Fore-reef	7	8.70	12.89	3.3-37.9
Co	Pre-monsoon	Aureed Is	Fore-reef	15	0.028	0.004	0.02-0.03
	Pre-monsoon	Campbell Is	Fore-reef	15	0.122	0.134	0.02-0.58
	Pre-monsoon	Campbell Is	Back-reef	15	0.073	0.070	0.02-0.26
	Post-monsoon	Aureed Is	Fore-reef	15	0.219	0.280	0.13-1.20
	Post-monsoon	Campbell Is	Fore-reef	7	0.170	0.077	0.13-0.33
Cr	Pre-monsoon	Aureed Is	Fore-reef	15	0.79	0.10	0.61-0.97
	Pre-monsoon	Campbell Is	Fore-reef	15	0.89	0.29	0.54-1.7
	Pre-monsoon	Campbell Is	Back-reef	15	1.15	0.60	0.72-2.8
	Post-monsoon	Aureed Is	Fore-reef	15	0.28	0.18	0.13-0.69
	Post-monsoon	Campbell Is	Fore-reef	7	0.54	0.74	0.13-2.2
Cu	Pre-monsoon	Aureed Is	Fore-reef	15	16.5	9.4	5.6-35.0
	Pre-monsoon	Campbell Is	Fore-reef	15	34.5	22.3	15.0-100
	Pre-monsoon	Campbell Is	Back-reef	15	31.1	15.5	11.0-75.0
	Post-monsoon	Aureed Is	Fore-reef	15	10.6	2.9	5.0-14.6
	Post-monsoon	Campbell Is	Fore-reef	7	15.6	9.3	8.9-33.2
Fe	Pre-monsoon	Aureed Is	Fore-reef	15	43.2	6.5	31.0-54.0
	Pre-monsoon	Campbell Is	Fore-reef	15	78.9	59.7	28.0-260
	Pre-monsoon	Campbell Is	Back-reef	15	200.3	210.3	44.0-680
	Post-monsoon	Aureed Is	Fore-reef	15	32.3	10.9	18.4-53.4
	Post-monsoon	Campbell Is	Fore-reef	7	22.4	4.5	13.0-26.0
Hg	Pre-monsoon	Aureed Is	Fore-reef	15	0.037	0.020	0.02-0.09
	Pre-monsoon	Campbell Is	Fore-reef	15	0.027	0.020	0.01-0.08
	Pre-monsoon	Campbell Is	Back-reef	15	0.025	0.009	0.01-0.05
	Post-monsoon	Aureed Is	Fore-reef	15	0.072	0.044	0.01-0.15
	Post-monsoon	Campbell Is	Fore-reef	7	0.017	0.010	<0.01-0.03

(Appendix Table 86 continued over)

Metal	Season	Sampling Station	Habitat	n	Mean	S.D.	Range
Mn	Pre-monsoon	Aureed Is	Fore-reef	15	13.6	5.9	7.3-27.0
	Pre-monsoon	Campbell Is	Fore-reef	15	24.3	13.7	9.4-52.0
	Pre-monsoon	Campbell Is	Back-reef	15	15.0	5.3	8.0-26.0
	Post-monsoon	Aureed Is	Fore-reef	15	23.8	10.7	11.4-49.5
	Post-monsoon	Campbell Is	Fore-reef	7	42.2	19.7	18.6-76.0
Ni	Pre-monsoon	Aureed Is	Fore-reef	15	0.55	0.39	0.32-1.9
	Pre-monsoon	Campbell Is	Fore-reef	15	2.20	1.95	0.15-6.7
	Pre-monsoon	Campbell Is	Back-reef	15	1.22	1.09	0.28-3.6
	Post-monsoon	Aureed Is	Fore-reef	15	0.37	0.32	0.25-1.3
	Post-monsoon	Campbell Is	Fore-reef	7	0.49	0.30	0.25-0.87
Pb	Pre-monsoon	Aureed Is	Fore-reef	15	0.163	0.040	0.09-0.24
	Pre-monsoon	Campbell Is	Fore-reef	15	0.167	0.076	0.07-0.40
	Pre-monsoon	Campbell Is	Back-reef	15	0.223	0.112	0.09-0.50
	Post-monsoon	Aureed Is	Fore-reef	15	0.268	0.193	0.20-0.90
	Post-monsoon	Campbell Is	Fore-reef	7	0.484	0.271	0.20-1.00
Se	Pre-monsoon	Aureed Is	Fore-reef	15	1.49	1.37	0.48-6.1
	Pre-monsoon	Campbell Is	Fore-reef	15	1.03	0.35	0.42-1.5
	Pre-monsoon	Campbell Is	Back-reef	15	1.44	0.81	0.89-3.4
	Post-monsoon	Aureed Is	Fore-reef	15	0.72	0.37	0.33-1.8
	Post-monsoon	Campbell Is	Fore-reef	7	0.75	0.85	0.63-0.88
Zn	Pre-monsoon	Aureed Is	Fore-reef	15	11.95	6.0	4.5-23.0
	Pre-monsoon	Campbell Is	Fore-reef	15	23.93	4.9	19.0-36.0
	Pre-monsoon	Campbell Is	Back-reef	15	24.11	13.8	6.9-60.0
	Post-monsoon	Aureed Is	Fore-reef	15	23.95	6.5	16.1-36.2
	Post-monsoon	Campbell Is	Fore-reef	7	30.13	7.4	20.7-41.6

Appendix Table 87. Analysis of Variance for differences in transformed metal concentration ($\log_e$(concentration+1)) in the body wall of the sea cucumber *S. chloronotus* from Aureed Island and Kokope Reef within two seasons.

Metal	Source of variation	DF	MS	F-ratio	Significance
Al	Season	1	0.560	0.383	p=0.553
	Station	1	7.786	10.879	p=0.050
	Season*Station	1	9.136	6.240	p=0.037
	Site{season*station}	8	1.464		
As	Season	1	3.133	10.879	p=0.011
	Station	1	1.115	3.870	p=0.085
	Season*Station	1	0.111	0.387	p=0.551
	Site{season*station}	8	0.288		
Cd	Season	1	0.037	1.481	p=0.258
	Station	1	0.005	0.204	p=0.663
	Season*Station	1	0.000	0.011	p=0.917
	Site{season*station}	8	0.025		
Co	Season	1	0.001	1.518	p=0.253
	Station	1	0.001	1.526	p=0.252
	Season*Station	1	0.005	11.145	p=0.010
	Site{season*station}	8	0.000		
Cr	Season	1	0.054	0.671	p=0.436
	Station	1	0.036	0.444	p=0.524
	Season*Station	1	0.004	0.055	p=0.821
	Site{season*station}	8	0.081		
Cu	Season	1	0.393	5.241	p=0.051
	Station	1	0.728	9.706	p=0.014
	Season*Station	1	1.316	17.545	p=0.003
	Site{season*station}	8	0.075		
Fe	Season	1	18.639	22.032	p=0.002
	Station	1	1.959	2.316	p=0.167
	Season*Station	1	14.135	16.708	p=0.003
	Site{season*station}	8	0.846		
Hg	Season	1	0.000	0.115	p=0.744
	Station	1	0.009	2.959	p=0.124
	Season*Station	1	0.001	0.238	p=0.639
	Site{season*station}	8	0.003		
Mn	Season	1	0.001	0.001	p=0.976
	Station	1	5.021	3.687	p=0.091
	Season*Station	1	0.992	0.728	p=0.418
	Site{season*station}	8	1.362		
Ni	Season	1	0.169	4.820	p=0.059
	Station	1	0.154	4.387	p=0.070
	Season*Station	1	0.007	0.208	p=0.660
	Site{season*station}	8	0.035		

(Appendix Table 87 continued over)

Metal	Source of variation	DF	MS	F-ratio	Significance
Pb	Season	1	0.005	0.461	p=0.561
	Station	1	0.137	13.680	p=0.006
	Season*Station	1	0.042	4.182	p=0.075
	Site{season*station}	8	0.010		
Se	Season	1	0.051	0.229	p=0.645
	Station	1	1.194	5.356	p=0.049
	Season*Station	1	0.639	2.865	p=0.129
	Site{season*station}	8	0.223		
Zn	Season	1	0.332	1.757	p=0.222
	Station	1	4.139	21.900	p=0.002
	Season*Station	1	0.641	3.390	p=0.103
	Site{season*station}	8	0.189		

Appendix Table 88. Trace metal concentrations within the body wall of the sea cucumber *S. chloronotus* from two locations within two seasons. Metal concentrations are in mg kg^{-1} (dry weight). n = sample size. S.D. = standard deviation. bdl = below detection limit.

Metal	Season	Sampling Station	n	Mean	S.D.	Range
Al	Pre-monsoon	Aureed Is	15	1.15	1.46	<0.02-5.4
	Pre-monsoon	Kokope Rf	15	11.0	17.8	3.6-75.0
	Post-monsoon	Aureed Is	14	2.38	0.75	1.4-4.2
	Post-monsoon	Kokope Rf	15	2.23	0.91	0.8-4.5
As	Pre-monsoon	Aureed Is	15	5.13	1.34	3.6-8.5
	Pre-monsoon	Kokope Rf	15	6.33	1.12	4.5-8.7
	Post-monsoon	Aureed Is	14	7.94	2.30	5.2-12.0
	Post-monsoon	Kokope Rf	15	12.05	3.72	6.3-18.0
Cd	Pre-monsoon	Aureed Is	15	0.112	0.048	0.07-0.23
	Pre-monsoon	Kokope Rf	15	0.096	0.039	0.05-0.18
	Post-monsoon	Aureed Is	14	0.186	0.173	0.09-0.78
	Post-monsoon	Kokope Rf	15	0.147	0.040	0.08-0.21
Co	Pre-monsoon	Aureed Is	15	0.071	0.010	0.06-0.10
	Pre-monsoon	Kokope Rf	15	0.058	0.016	0.05-0.11
	Post-monsoon	Aureed Is	14	0.043	0.005	0.04-0.05
	Post-monsoon	Kokope Rf	15	0.071	0.008	0.06-0.08
Cr	Pre-monsoon	Aureed Is	15	0.609	0.502	0.38-2.40
	Pre-monsoon	Kokope Rf	15	0.466	0.106	0.26-0.70
	Post-monsoon	Aureed Is	14	0.446	0.047	0.34-0.53
	Post-monsoon	Kokope Rf	15	0.403	0.094	0.22-0.52
Cu	Pre-monsoon	Aureed Is	15	0.88	0.11	0.7-1.1
	Pre-monsoon	Kokope Rf	15	2.18	0.36	1.4-2.8
	Post-monsoon	Aureed Is	14	1.98	0.16	1.8-2.4
	Post-monsoon	Kokope Rf	15	1.77	0.21	1.5-2.1
Fe	Pre-monsoon	Aureed Is	15	9.5	4.3	4.4-18
	Pre-monsoon	Kokope Rf	15	44.1	43.8	23-200
	Post-monsoon	Aureed Is	14	84.3	37.6	39-160
	Post-monsoon	Kokope Rf	15	50.2	36.9	18-160
Hg	Pre-monsoon	Aureed Is	15	0.010	0.000	0.01-0.01
	Pre-monsoon	Kokope Rf	15	0.043	0.026	0.02-0.11
	Post-monsoon	Aureed Is	14	0.012	0.006	<0.02-0.03
	Post-monsoon	Kokope Rf	15	0.031	0.035	<0.02-0.14
Mn	Pre-monsoon	Aureed Is	15	0.83	0.38	0.4-1.6
	Pre-monsoon	Kokope Rf	15	3.48	2.21	2.2-11.0
	Post-monsoon	Aureed Is	14	1.36	0.22	1.1-1.8
	Post-monsoon	Kokope Rf	15	2.54	1.38	0.5-5.3

(Appendix Table 88 continued over)

Metal	Season	Sampling Station	n	Mean	S.D.	Range
Ni	Pre-monsoon	Aureed Is	15	0.855	0.327	0.63-2.00
	Pre-monsoon	Kokope Rf	15	0.645	0.325	0.34-1.40
	Post-monsoon	Aureed Is	14	0.614	0.064	0.52-0.74
	Post-monsoon	Kokope Rf	15	0.491	0.099	0.32-0.71
Pb	Pre-monsoon	Aureed Is	15	0.026	0.014	0.01-0.06
	Pre-monsoon	Kokope Rf	15	0.193	0.064	0.09-0.30
	Post-monsoon	Aureed Is	14	0.066	0.047	0.02-0.20
	Post-monsoon	Kokope Rf	15	0.112	0.070	0.04-0.22
Se	Pre-monsoon	Aureed Is	15	4.22	0.97	3.0-6.8
	Pre-monsoon	Kokope Rf	15	4.62	0.90	3.2-6.4
	Post-monsoon	Aureed Is	14	3.49	0.90	2.3-4.8
	Post-monsoon	Kokope Rf	15	6.35	1.15	4.2-8.1
Zn	Pre-monsoon	Aureed Is	15	4.92	1.55	3.2-9.1
	Pre-monsoon	Kokope Rf	15	7.37	2.95	4.7-13.0
	Post-monsoon	Aureed Is	14	4.49	1.03	3.3-7.0
	Post-monsoon	Kokope Rf	15	11.05	4.91	6.2-26.0

Appendix Table 89. Analysis of Variance for differences in transformed metal concentration ($\log_e$(concentration+1)) in the liver of the reef fish *L. carponotatus* from Aureed Island within two seasons.

Metal	Source of variation	DF	MS	F-ratio	Significance
Al	Season	1	0.192	0.571	p=0.456
	Error	28	0.336		
As	Season	1	0.505	1.423	p=0.243
	Error	28	0.355		
Cd	Season	1	0.524	1.505	p=0.230
	Error	28	0.348		
Co	Season	1	0.273	19.362	p<0.001
	Error	28	0.014		
Cr	Season	1	0.643	46.847	p<0.001
	Error	28	0.014		
Cu	Season	1	0.256	1.599	p=0.216
	Error	28	0.160		
Fe	Season	1	0.002	0.008	p=0.929
	Error	28	0.283		
Hg	Season	1	0.291	7.795	p=0.009
	Error	28	0.166		
Mn	Season	1	0.120	4.635	p=0.040
	Error	28	0.026		
Ni	Season	1	0.104	56.104	p<0.001
	Error	28	0.002		
Pb	Season	1	0.924	14.979	p=0.001
	Error	28	0.062		
Se	Season	1	0.422	3.622	p=0.067
	Error	28	0.117		
Zn	Season	1	0.015	0.425	p=0.520
	Error	28	0.034		

Appendix Table 90. Analysis of Variance for differences in transformed metal concentration ($\log_e$(concentration+1)) in the liver of the reef fish *L. carponotatus* from Aureed Island and Kokope Reef during the post-monsoon season.

Metal	Source of variation	DF	MS	F-ratio	Significance
Al	Station	1	0.002	0.004	p=0.950
	Error	28	0.547		
As	Station	1	2.346	3.965	p=0.056
	Error	28	0.592		
Cd	Station	1	7.435	20.553	p<0.001
	Error	28	0.362		
Co	Station	1	0.035	12.301	p=0.002
	Error	28	0.003		
Cr	Station	1	18.977	63.880	p<0.001
	Error	28	0.297		
Cu	Station	1	0.527	6.840	p=0.014
	Error	28	0.077		
Fe	Station	1	0.038	0.127	p=0.724
	Error	28	0.296		
Hg	Station	1	0.001	0.031	p=0.861
	Error	28	0.038		
Mn	Station	1	0.127	3.165	p=0.086
	Error	28	0.040		
Ni	Station	1	0.230	5.536	p=0.026
	Error	28	0.042		
Pb	Station	1	0.767	12.842	p=0.001
	Error	28	0.060		
Se	Station	1	0.000	0.000	p=0.990
	Error	28	0.095		
Zn	Station	1	0.711	25.478	p<0.001
	Error	28	0.028		

Appendix Table 91. Analysis of Variance for differences in transformed metal concentration ($\log_e$(concentration+1)) in the reef fish *L. carponotatus* from Aureed Island within two tissues (liver and muscle).

Metal	Source of variation	DF	MS	F-ratio	Significance
Al	Tissue	1	0.258	1.041	p=0.316
	Error	28	0.247		
As	Tissue	1	5.556	11.652	p=0.002
	Error	28	0.477		
Cd	Tissue	1	105.680	726.782	p<0.001
	Error	28	0.145		
Co	Tissue	1	0.296	26.220	p<0.001
	Error	28	0.011		
Cr	Tissue	1	0.252	6.764	p=0.015
	Error	28	0.037		
Cu	Tissue	1	58.662	435.697	p<0.001
	Error	28	0.135		
Fe	Tissue	1	137.728	1118.479	p<0.001
	Error	28	0.123		
Hg	Tissue	1	0.525	3.004	p=0.094
	Error	28	0.175		
Mn	Tissue	1	19.926	1268.940	p<0.001
	Error	28	0.016		
Ni	Tissue	1	0.459	16.029	p<0.001
	Error	28	0.029		
Pb	Tissue	1	0.125	28.709	p<0.001
	Error	28	0.004		
Se	Tissue	1	11.510	150.377	p<0.001
	Error	28	0.077		
Zn	Tissue	1	42.918	1511.585	p<0.001
	Error	28	0.028		

Appendix Table 92. Trace metal concentrations within liver and muscle tissue of the reef fish *L. carponotatus* from two locations within two seasons. Metal concentrations are in mg kg^{-1} (dry weight). n = sample size. S.D. = standard deviation. bdl = below detection limit.

Metal	Season	Sampling Station	Tissue	n	Mean	S.D.	Range
Al	Pre-monsoon	Aureed Is	Liver	15	5.45	2.84	1.4-11.0
	Pre-monsoon	Aureed Is	Muscle	15	4.87	5.68	2.2-25.0
	Post-monsoon	Aureed Is	Liver	15	7.22	4.78	1.3-18.9
	Post-monsoon	Kokope Rf	Liver	15	8.09	6.18	1.3-19.6
As	Pre-monsoon	Aureed Is	Liver	15	30.5	22.5	6.9-86.0
	Pre-monsoon	Aureed Is	Muscle	15	12.7	9.1	1.7-29.0
	Post-monsoon	Aureed Is	Liver	15	21.7	12.4	8.0-49.0
	Post-monsoon	Kokope Rf	Liver	15	15.3	13.1	2.5-47.0
Cd	Pre-monsoon	Aureed Is	Liver	15	51.2	35.1	16.0-162
	Pre-monsoon	Aureed Is	Muscle	15	0.05	0.01	0.05-0.08
	Post-monsoon	Aureed Is	Liver	15	41.9	34.6	17.0-140
	Post-monsoon	Kokope Rf	Liver	15	13.6	7.5	4.0- 27.8
Co	Pre-monsoon	Aureed Is	Liver	15	0.48	0.24	0.21-1.1
	Pre-monsoon	Aureed Is	Muscle	15	0.20	0.00	0.20-0.20
	Post-monsoon	Aureed Is	Liver	15	0.21	0.09	0.13-0.39
	Post-monsoon	Kokope Rf	Liver	15	bdl		<0.25
Cr	Pre-monsoon	Aureed Is	Liver	15	0.63	0.11	0.45-0.93
	Pre-monsoon	Aureed Is	Muscle	15	0.41	0.52	0.20-2.2
	Post-monsoon	Aureed Is	Liver	15	0.23	0.22	<0.25-0.86
	Post-monsoon	Kokope Rf	Liver	15	6.63	5.45	0.50-21.1
Cu	Pre-monsoon	Aureed Is	Liver	15	42.7	22.9	19.0-95.0
	Pre-monsoon	Aureed Is	Muscle	15	1.4	0.5	0.7- 2.6
	Post-monsoon	Aureed Is	Liver	15	47.8	15.2	32.8-85.6
	Post-monsoon	Kokope Rf	Liver	15	36.1	9.4	19.2-54.3
Fe	Pre-monsoon	Aureed Is	Liver	15	1393.3	534.9	580-2400
	Pre-monsoon	Aureed Is	Muscle	15	17.4	5.3	11.0-31.0
	Post-monsoon	Aureed Is	Liver	15	1480.5	765.6	322-2894
	Post-monsoon	Kokope Rf	Liver	15	1293.2	559.8	557-2562
Hg	Pre-monsoon	Aureed Is	Liver	15	1.68	1.75	0.26-5.80
	Pre-monsoon	Aureed Is	Muscle	15	0.80	0.40	0.31-1.44
	Post-monsoon	Aureed Is	Liver	15	0.53	0.26	0.06-0.93
	Post-monsoon	Kokope Rf	Liver	15	0.53	0.37	0.11-1.50
Mn	Pre-monsoon	Aureed Is	Liver	15	5.29	1.02	3.9-7.5
	Pre-monsoon	Aureed Is	Muscle	15	0.22	0.09	0.1-0.5
	Post-monsoon	Aureed Is	Liver	15	4.54	0.86	3.1-5.9
	Post-monsoon	Kokope Rf	Liver	15	3.93	1.26	2.3-7.5

(Appendix Table 92 continued over)

Metal	Season	Sampling Station	Tissue	n	Mean	S.D.	Range
Ni	Pre-monsoon	Aureed Is	Liver	15	0.13	0.04	0.06-0.20
	Pre-monsoon	Aureed Is	Muscle	15	0.49	0.47	0.30-2.10
	Post-monsoon	Aureed Is	Liver	15	bdl		<0.5
	Post-monsoon	Kokope Rf	Liver	15	0.57	0.50	<0.5-1.50
Pb	Pre-monsoon	Aureed Is	Liver	15	0.17	0.08	0.09-0.36
	Pre-monsoon	Aureed Is	Muscle	15	0.33	0.10	0.30-0.70
	Post-monsoon	Aureed Is	Liver	15	0.76	0.74	<0.4-2.9
	Post-monsoon	Kokope Rf	Liver	15	bdl		<0.4
Se	Pre-monsoon	Aureed Is	Liver	15	9.28	3.65	4.1-16.0
	Pre-monsoon	Aureed Is	Muscle	15	1.83	0.37	1.2- 2.3
	Post-monsoon	Aureed Is	Liver	15	6.96	2.23	2.7-10.9
	Post-monsoon	Kokope Rf	Liver	15	7.01	2.97	4.0-16.5
Zn	Pre-monsoon	Aureed Is	Liver	15	160.7	34.7	110-220
	Pre-monsoon	Aureed Is	Muscle	15	13.5	1.5	12- 17
	Post-monsoon	Aureed Is	Liver	15	152.0	23.5	120-209
	Post-monsoon	Kokope Rf	Liver	15	112.1	21.3	82-155

Appendix Table 93. Analysis of Variance for differences in transformed (log_e(concentration+1)) metal concentration in the whole soft tissue of the cockle *P. erosa* from Boigu and Saibai Islands within two seasons.

Metal	Source of variation	DF	MS	F-ratio	Significance
Al	Season	1	0.195	0.067	p=0.802
	Station	1	26.062	9.043	p=0.017
	Season*station	1	0.101	0.035	p=0.857
	Site{season*station}	8	2.882		
As	Season	1	1.432	3.606	p=0.094
	Station	1	1.451	3.654	p=0.092
	Season*station	1	0.612	1.541	p=0.250
	Site{season*station}	8	0.397		
Cd	Season	1	0.244	1.988	p=0.196
	Station	1	1.229	9.994	p=0.013
	Season*station	1	0.019	0.158	p=0.702
	Site{season*station}	8	0.123		
Co	Season	1	0.256	1.516	p=0.253
	Station	1	0.554	3.279	p=0.108
	Season*station	1	0.238	1.407	p=0.270
	Site{season*station}	8	0.169		
Cr	Season	1	0.121	0.205	p=0.662
	Station	1	1.765	2.986	p=0.122
	Season*station	1	0.003	0.004	p=0.949
	Site{season*station}	8	0.591		
Cu	Season	1	1.658	17.448	p=0.003
	Station	1	1.384	14.569	p=0.005
	Season*station	1	0.033	0.352	p=0.569
	Site{season*station}	8	0.095		
Fe	Season	1	0.831	1.308	p=0.286
	Station	1	3.207	5.051	p=0.055
	Season*station	1	0.139	0.219	p=0.652
	Site{season*station}	8	0.635		
Hg	Season	1	0.069	6.309	p=0.036
	Station	1	0.031	2.780	p=0.134
	Season*station	1	0.015	1.386	p=0.273
	Site{season*station}	8	0.011		
Mn	Season	1	0.021	0.012	p=0.914
	Station	1	23.726	13.998	p=0.006
	Season*station	1	0.000	0.000	p=0.989
	Site{season*station}	8	1.695		
Ni	Season	1	3.000	2.062	p=0.189
	Station	1	0.121	0.083	p=0.780
	Season*station	1	0.278	0.191	p=0.673
	Site{season*station}	8	1.455		

(Appendix Table 93 continued over)

Metal	Source of variation	DF	MS	F-ratio	Significance
Pb	Season	1	0.005	0.012	p=0.915
	Station	1	0.126	0.332	p=0.580
	Season*station	1	0.001	0.002	p=0.970
	Site{season*station}	8	0.380		
Se	Season	1	0.928	2.689	p=0.140
	Station	1	1.622	4.700	p=0.062
	Season*station	1	0.069	0.199	p=0.667
	Site{season*station}	8	0.345		
Zn	Season	1	0.179	0.106	p=0.753
	Station	1	1.636	0.974	p=0.353
	Season*station	1	0.009	0.005	p=0.943
	Site{season*station}	8	1.680		

Appendix Table 94. Analysis of variance for changes in transformed (log_e(concentration+1)) metal concentration in the whole soft tissue of the cockle *P. erosa* from Boigu and Saibai Islands, Saibai Village, and Shelburne Bay during the pre-monsoon season.

Metal	Source of variation	DF	MS	F-ratio	Significance
Al	Station	3	9.500	15.194	p=0.002
	Site{station}	7	0.625		
As	Station	3	5.681	42.884	p<0.001
	Site{station}	7	0.132		
Cd	Station	3	1.149	50.351	p<0.001
	Site{station}	7	0.023		
Co	Station	3	1.367	16.809	p=0.001
	Site{station}	7	0.081		
Cr	Station	3	0.399	1.890	p=0.220
	Site{station}	7	0.211		
Cu	Station	3	1.028	8.723	p=0.009
	Site{station}	7	0.118		
Fe	Station	3	5.658	20.943	p=0.001
	Site{station}	7	0.270		
Hg	Station	3	0.026	7.104	p=0.016
	Site{station}	7	0.004		
Mn	Station	3	17.026	73.353	p<0.001
	Site{station}	7	0.232		
Ni	Station	3	2.570	9.823	p=0.007
	Site{station}	7	0.262		
Pb	Station	3	0.239	1.890	p=0.220
	Site{station}	7	0.127		
Se	Station	3	0.367	10.320	p=0.006
	Site{station}	7	0.036		
Zn	Station	3	0.411	1.421	p=0.315
	Site{station}	7	0.289		

Appendix Table 95. Analysis of Variance for differences in transformed ($\log_e$(concentration+1)) metal concentration in the whole soft tissue of the cockle *P. erosa* from Boigu, Saibai and Parama Islands, and two stations along the Papua New Guinea coast (Aberemuba Village and West Aberemuba) during the post-monsoon season.

Metal	Source of variation	DF	MS	F-ratio	Significance
Al	Station	4	31.506	26.120	p<0.001
	Site{station}	8	1.206		
As	Station	4	0.064	1.525	p=0.283
	Site{station}	8	0.042		
Cd	Station	4	0.534	10.403	p=0.001
	Site{station}	8	0.051		
Co	Station	4	1.213	24.825	p<0.001
	Site{station}	8	0.049		
Cr	Station	4	1.932	23.839	p<0.001
	Site{station}	8	0.081		
Cu	Station	4	1.271	5.308	p=0.022
	Site{station}	8	0.239		
Fe	Station	4	1.913	11.091	p=0.002
	Site{station}	8	0.172		
Hg	Station	4	0.023	1.622	p=0.260
	Site{station}	8	0.014		
Mn	Station	4	18.746	32.870	p<0.001
	Site{station}	8	0.570		
Ni	Station	4	1.882	5.579	p=0.019
	Site{station}	8	0.337		
Pb	Station	4	2.024	76.047	p<0.001
	Site{station}	8	0.027		
Se	Station	4	0.392	6.113	p=0.015
	Site{station}	8	0.064		
Zn	Station	4	1.341	2.574	p=0.119
	Site{station}	8	0.521		

Appendix Table 96. Aluminium (Al) concentrations in the whole soft tissue of the cockle *P. erosa* from different locations within two seasons. Metal concentrations are in mg kg^{-1} (dry weight). Means with the same superscript indicate a significant difference between locations within the same season ($p<=0.05$ by Tukey's Test). n = sample size. S.D. = standard deviation.

Season	Sampling Station	n	Mean	S.D.	Range
Pre-monsoon	Boigu Is	15	134.3^{ab}	47.4	60.0-228
Pre-monsoon	Saibai Is	15	34.8^{ac}	20.8	13.0-90.0
Pre-monsoon	Saibai Village	16	58.5^{bcd}	68.3	17.0-271
Pre-monsoon	Shelburne Bay	9	245.0^{cd}	136.4	58.0-444
Post-monsoon	Boigu Is	15	229.7^{e}	391.5	59.0-1600
Post-monsoon	Saibai Is	15	59.5^{f}	61.1	7.1-220
Post-monsoon	West Aberemuba	15	2385.3^{efgh}	1410.2	430-4400
Post-monsoon	Aberemuba Village	15	148.6^{g}	156.5	17.0-630
Post-monsoon	Parama Is	6	280.0^{h}	323.6	33.0-890

Appendix Table 97. Arsenic (As) concentrations in the whole soft tissue of the cockle *P. erosa* from different locations within two seasons. Metal concentrations are in mg kg^{-1} (dry weight). Means with the same superscript indicate a significant difference between locations within the same season ($p<=0.05$ by Tukey's Test). n = sample size. S.D. = standard deviation.

Season	Sampling Station	n	Mean	S.D.	Range
Pre-monsoon	Boigu Is	15	5.28^{ab}	0.53	4.4-6.0
Pre-monsoon	Saibai Is	15	9.81^{ac}	3.19	6.8-18.0
Pre-monsoon	Saibai Village	16	6.99^{d}	1.90	4.3-12.0
Pre-monsoon	Shelburne Bay	9	32.11^{bcd}	7.46	21.0-47.0
Post-monsoon	Boigu Is	15	9.76	2.66	4.6-15.0
Post-monsoon	Saibai Is	15	10.92	2.73	7.2-15.0
Post-monsoon	West Aberemuba	15	8.95	1.49	6.9-13.0
Post-monsoon	Aberemuba Village	15	9.49	2.23	6.3-16.0
Post-monsoon	Parama Is	6	9.23	3.30	5.0-13.0

Appendix Table 98. Cadmium (Cd) concentrations in the whole soft tissue of the cockle *P. erosa* from different locations within two seasons. Metal concentrations are in mg kg^{-1} (dry weight). Means with the same superscript indicate a significant difference between locations within the same season ($p<=0.05$ by Tukey's Test). n = sample size. S.D. = standard deviation.

Season	Sampling Station	n	Mean	S.D.	Range
Pre-monsoon	Boigu Is	15	0.06^{ab}	0.02	0.05-0.11
Pre-monsoon	Saibai Is	15	0.39^{ac}	0.32	0.07-1.10
Pre-monsoon	Saibai Village	16	1.20^{bcd}	1.51	0.23-6.70
Pre-monsoon	Shelburne Bay	9	0.13^{d}	0.05	0.05-0.18
Post-monsoon	Boigu Is	15	0.16^{e}	0.04	0.11-0.23
Post-monsoon	Saibai Is	15	0.63^{e}	0.31	0.23-1.30
Post-monsoon	West Aberemuba	15	0.27	0.30	0.02-1.30
Post-monsoon	Aberemuba Village	15	0.49	0.43	0.16-1.90
Post-monsoon	Parama Is	6	0.17	0.17	0.06-0.51

Appendix Table 99. Cobalt (Co) concentrations in the whole soft tissue of the cockle *P. erosa* from different locations within two seasons. Metal concentrations are in mg kg^{-1} (dry weight). Means with the same superscript indicate a significant difference between locations within the same season ($p<=0.05$ by Tukey's Test). n = sample size. S.D. = standard deviation.

Season	Sampling Station	n	Mean	S.D.	Range
Pre-monsoon	Boigu Is	15	1.10^{a}	0.35	0.55-1.6
Pre-monsoon	Saibai Is	15	2.02^{b}	1.15	0.59-4.8
Pre-monsoon	Saibai Village	16	0.75^{bc}	0.31	0.35-1.3
Pre-monsoon	Shelburne Bay	9	2.69^{ac}	0.80	1.20-4.0
Post-monsoon	Boigu Is	15	1.71^{de}	0.44	0.97-2.4
Post-monsoon	Saibai Is	15	1.91^{f}	0.54	1.2-3.1
Post-monsoon	West Aberemuba	15	4.51^{efgh}	2.02	2.5-10.0
Post-monsoon	Aberemuba Village	15	2.75^{dgi}	1.12	1.3-5.4
Post-monsoon	Parama Is	6	1.52^{hi}	0.86	0.52-2.7

Appendix Table 100. Chromium (Cr) concentrations in the whole soft tissue of the cockle *P. erosa* from different locations within two seasons. Metal concentrations are in mg kg^{-1} (dry weight). Means with the same superscript indicate a significant difference between locations within the same season ($p<=0.05$ by Tukey's Test). n = sample size. S.D. = standard deviation.

Season	Sampling Station	n	Mean	S.D.	Range
Pre-monsoon	Boigu Is	15	1.92	1.70	0.82-6.4
Pre-monsoon	Saibai Is	15	0.88	0.39	0.31-1.5
Pre-monsoon	Saibai Village	16	1.03	0.42	0.54-2.0
Pre-monsoon	Shelburne Bay	9	2.02	2.74	0.73-9.3
Post-monsoon	Boigu Is	15	1.52^{a}	0.93	0.46-3.7
Post-monsoon	Saibai Is	15	0.74^{b}	0.37	0.40-1.9
Post-monsoon	West Aberemuba	15	3.69^{abcd}	2.33	1.3-11.0
Post-monsoon	Aberemuba Village	15	1.13^{c}	0.78	0.42-3.3
Post-monsoon	Parama Is	6	0.86^{d}	0.38	0.38-1.4

Appendix Table 101. Copper (Cu) concentrations in the whole soft tissue of the cockle *P. erosa* from different locations within two seasons. Metal concentrations are in mg kg^{-1} (dry weight). Means with the same superscript indicate a significant difference between locations within the same season ($p<=0.05$ by Tukey's Test). n = sample size. S.D. = standard deviation.

Season	Sampling Station	n	Mean	S.D.	Range
Pre-monsoon	Boigu Is	15	6.73^{a}	2.03	4.2-9.7
Pre-monsoon	Saibai Is	15	4.87^{b}	0.94	2.3-6.3
Pre-monsoon	Saibai Village	16	7.51	3.20	3.5-15.0
Pre-monsoon	Shelburne Bay	9	11.50^{ab}	4.67	4.9-21.0
Post-monsoon	Boigu Is	15	10.19	2.39	6.2-14.0
Post-monsoon	Saibai Is	15	6.79^{c}	1.23	4.4-9.5
Post-monsoon	West Aberemuba	15	17.52^{c}	11.57	9.8-57.0
Post-monsoon	Aberemuba Village	15	14.41	7.33	5.1-36.0
Post-monsoon	Parama Is	6	14.72	14.16	3.6-41.0

Appendix Table 102. Iron (Fe) concentrations in the whole soft tissue of the cockle *P. erosa* from different locations within two seasons. Metal concentrations are in mg kg^{-1} (dry weight). Means with the same superscript indicate a significant difference between locations within the same season ($p<=0.05$ by Tukey's Test). n = sample size. S.D. = standard deviation.

Season	Sampling Station	n	Mean	S.D.	Range
Pre-monsoon	Boigu Is	15	2964.3^{a}	1074.5	795-4820
Pre-monsoon	Saibai Is	15	2327.6^{b}	1724.1	708-7310
Pre-monsoon	Saibai Village	16	2382.3^{c}	1749.9	677-8160
Pre-monsoon	Shelburne Bay	9	580.1^{abc}	264.6	253-977
Post-monsoon	Boigu Is	15	4133.3^{de}	1479.2	1100-6200
Post-monsoon	Saibai Is	15	2433.3^{df}	1153.7	1000-5000
Post-monsoon	West Aberemuba	15	4913.3^{fg}	2168.2	1600-8800
Post-monsoon	Aberemuba Village	15	2962.0	1433.9	1100-7300
Post-monsoon	Parama Is	6	1950.0^{eg}	1917.2	690-5800

Appendix Table 103. Mercury (Hg) concentrations in the whole soft tissue of the cockle *P. erosa* from different locations within two seasons. Metal concentrations are in mg kg^{-1} (dry weight). Means with the same superscript indicate a significant difference between locations within the same season ($p<=0.05$ by Tukey's Test). n = sample size. S.D. = standard deviation. bdl = below detection limit.

Season	Sampling Station	n	Mean	S.D.	Range
Pre-monsoon	Boigu Is	15	0.16^{a}	0.03	0.11-0.23
Pre-monsoon	Saibai Is	15	0.18^{b}	0.08	0.03-0.34
Pre-monsoon	Saibai Village	16	0.12	0.09	0.05-0.34
Pre-monsoon	Shelburne Bay	9	$<0.10^{ab}$	bdl	bdl
Post-monsoon	Boigu Is	15	0.20	0.06	0.12-0.32
Post-monsoon	Saibai Is	15	0.30	0.13	0.16-0.62
Post-monsoon	West Aberemuba	15	0.28	0.24	0.09-0.91
Post-monsoon	Aberemuba Village	15	0.30	0.17	0.16-0.79
Post-monsoon	Parama Is	6	0.18	0.14	0.08-0.39

Appendix Table 104. Manganese (Mn) concentrations in the whole soft tissue of the cockle *P. erosa* from different locations within two seasons. Metal concentrations are in mg kg^{-1} (dry weight). Means with the same superscript indicate a significant difference between locations within the same season ($p<=0.05$ by Tukey's Test). n = sample size. S.D. = standard deviation.

Season	Sampling Station	n	Mean	S.D.	Range
Pre-monsoon	Boigu Is	15	18.01^{abc}	6.13	6.0-30.0
Pre-monsoon	Saibai Is	15	77.67^{ad}	49.49	18.0-185
Pre-monsoon	Saibai Village	16	43.38^{be}	28.26	16.0-128
Pre-monsoon	Shelburne Bay	9	2.71^{cde}	0.96	1.3-4.4
Post-monsoon	Boigu Is	15	20.59^{fghi}	12.61	6.2-47.0
Post-monsoon	Saibai Is	15	90.07^{fjk}	68.38	16.0-230
Post-monsoon	West Aberemuba	15	128.5^{gl}	87.89	23.0-330
Post-monsoon	Aberemuba Village	15	456.0^{hjl}	324.7	120-1300
Post-monsoon	Parama Is	6	310.0^{ik}	232.4	110-720

Appendix Table 105. Nickel (Ni) concentrations in the whole soft tissue of the cockle *P. erosa* from different locations within two seasons. Metal concentrations are in mg kg^{-1} (dry weight). Means with the same superscript indicate a significant difference between locations within the same season ($p<=0.05$ by Tukey's Test). n = sample size. S.D. = standard deviation.

Season	Sampling Station	n	Mean	S.D.	Range
Pre-monsoon	Boigu Is	15	3.37^{a}	2.83	1.6-13.0
Pre-monsoon	Saibai Is	15	5.06^{b}	5.40	1.1-23.0
Pre-monsoon	Saibai Village	16	2.35^{c}	0.83	1.3-4.8
Pre-monsoon	Shelburne Bay	9	10.33^{abc}	6.99	3.8-28.0
Post-monsoon	Boigu Is	15	6.22	1.77	3.5-9.0
Post-monsoon	Saibai Is	15	7.29	8.05	2.8-35.0
Post-monsoon	West Aberemuba	15	15.36^{d}	12.39	5.2-49.0
Post-monsoon	Aberemuba Village	15	8.74	8.55	2.0-31.0
Post-monsoon	Parama Is	6	4.28^{d}	4.94	0.7-14.0

Appendix Table 106. Lead (Pb) concentrations in the whole soft tissue of the cockle *P. erosa* from different locations within two seasons. Metal concentrations are in mg kg^{-1} (dry weight). Means with the same superscript indicate a significant difference between locations within the same season ($p<=0.05$ by Tukey's Test). n = sample size. S.D. = standard deviation.

Season	Sampling Station	n	Mean	S.D.	Range
Pre-monsoon	Boigu Is	15	0.63	0.49	0.18-2.2
Pre-monsoon	Saibai Is	15	0.49	0.38	0.08-1.1
Pre-monsoon	Saibai Village	16	0.98	0.58	0.26-2.7
Pre-monsoon	Shelburne Bay	9	0.55	0.28	0.22-0.94
Post-monsoon	Boigu Is	15	0.64^{abc}	0.31	0.30-1.3
Post-monsoon	Saibai Is	15	0.48^{def}	0.21	0.16-0.85
Post-monsoon	West Aberemuba	15	2.97^{adgh}	1.28	1.1-4.7
Post-monsoon	Aberemuba Village	15	1.06^{beg}	0.53	0.32-2.3
Post-monsoon	Parama Is	6	1.24^{cfh}	0.54	0.59-2.1

Appendix Table 107. Selenium (Se) concentrations in the whole soft tissue of the cockle *P. erosa* from different locations within two seasons. Metal concentrations are in mg kg^{-1} (dry weight). Means with the same superscript indicate a significant difference between locations within the same season ($p<=0.05$ by Tukey's Test). n = sample size. S.D. = standard deviation.

Season	Sampling Station	n	Mean	S.D.	Range
Pre-monsoon	Boigu Is	15	3.75^{a}	0.41	2.9-4.4
Pre-monsoon	Saibai Is	15	2.71^{ab}	0.73	2.0-4.4
Pre-monsoon	Saibai Village	16	3.42	0.87	2.1-5.9
Pre-monsoon	Shelburne Bay	9	4.62^{b}	0.89	3.5-6.4
Post-monsoon	Boigu Is	15	5.63^{cd}	1.42	3.6-8.7
Post-monsoon	Saibai Is	15	3.47^{c}	0.97	1.7-4.9
Post-monsoon	West Aberemuba	15	3.61^{d}	0.88	2.4-5.5
Post-monsoon	Aberemuba Village	15	4.44	1.14	2.4-6.4
Post-monsoon	Parama Is	6	3.53	0.73	2.9-4.8

Appendix Table 108. Zinc (Zn) concentrations in the whole soft tissue of the cockle *P. erosa* from different locations within two seasons. Metal concentrations are in mg kg^{-1} (dry weight). Means with the same superscript indicate a significant difference between locations within the same season ($p<=0.05$ by Tukey's Test). n = sample size. S.D. = standard deviation.

Season	**Sampling Station**	**n**	**Mean**	**S.D.**	**Range**
Pre-monsoon	Boigu Is	15	419.6	165.7	158-724
Pre-monsoon	Saibai Village	16	437.6	161.6	168-732
Pre-monsoon	Saibai Is	15	313.1	133.4	139-589
Pre-monsoon	Shelburne Bay	9	422.6	114.5	269-596
Post-monsoon	Boigu Is	15	478.7	167.3	140-720
Post-monsoon	Saibai Is	15	366.0	206.7	110-790
Post-monsoon	West Aberemuba	15	569.3	253.6	220-990
Post-monsoon	Aberemuba Village	15	357.5	182.7	65-590
Post-monsoon	Parama Is	6	236.3	116.2	78-380